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VIBRATION SURVEY OF IPNS BEAM LINE MAGNETS AND EXPERIMENT HALL

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1.0 INTRODUCTION

Successful operation of the 7-GeV Advanced Photon Source (APS) requires that vibration (self-induced or transmitted via the floor/support system) of the quadrupole magnets be eliminated or otherwise controlled within allowable limits. The acceptance criterion is based on vertical emittance growth. In particular, it is required that

$$\frac{\Delta\varepsilon_z}{\varepsilon_z} < 10\% \tag{1}$$

Low frequency (< 20 Hz) vibrations lead to position and photon beam steering which can be corrected for with feedback systems using steering magnets. Higher frequency vibrations will lead to effective emittance growth.

Magnification factors relating closed orbit distortions and quadrupole magnet vibration were developed for several types of vibration [1]. Of these types the most stringent criteria required to satisfy Eq. (1) are

$$\begin{aligned} (\delta_m)_V &< 0.12\ \mu m \\ (\delta_m)_H &< 0.34\ \mu m \end{aligned} \tag{2}$$

where $(\delta_m)_V$ and $(\delta_m)_H$ are the vertical and horizontal components, respectively, of quadrupole magnet vibration. Since vibrations at frequencies less than 20 Hz can be corrected for using steering magnets, these criteria apply for frequencies greater than 20 Hz.

There are a number of possible excitation sources both internal and external to the experiment hall that must be considered in the design of the 7-GeV APS. To gain insights as to the level, frequency content, and transmission of vibration at a typical accelerator facility, a vibration survey of the ANL Intense Pulsed Neutron Source (IPNS) facility was planned and carried out. Unlike the 7-GeV APS, it is understood that the IPNS was not designed to meet specific vibration criteria.

Before discussing the vibration survey of the IPNS, it should be noted that at the National Laboratory for High Energy Physics (KEK) in Japan, Katsura et al. [2] measured the vibration amplitude of the synchrotron-radiation (SR) axis of the 2.5-GeV electron storage ring of the Photon Factory. They observed that the measured vibration amplitude was about 10 μm at a point 12 m from the bending magnet source point. Recognizing that vibration amplitudes on the order of 10 μm will compromise the usefulness of the next generation, low emittance type storage ring, it was important that the cause of the vibrations be found. Toward this end, Huke [3] measured the vibration of the 2.5-GeV ring tunnel floor and identified various vibration noise sources.

The noise sources studied included air-conditioners, evacuation system, fans, and refrigerators. The maximum amplitude of discrete frequency components of ring tunnel floor motion varied from 0.002 to 0.081 μm, for frequency components in the range 14 to 50 Hz. Most of the frequency components could be related to a specific excitation source. Huke [3] notes that a small displacement of the quadrupole magnet results in a large distortion of the closed orbit. As an example, he cites the case of the 20.5 Hz component of floor motion, with a measured amplitude of 0.08 μm, exciting an SR axis vibration of 2.0 μm ("measured at a point 12 m from the SR source point"); this represents a magnification factor of 150. As possible, results from the subject study will be compared in a qualitative sense with the results from Huke's vibration survey at KEK.

2.0 OBJECTIVE

The overall objective of the vibration survey of the IPNS is to obtain vibration data and insights to support the vibration study of the APS. Specific objectives of each of six independent tests are given below in Section 4.0.

3.0 VIBRATION EXCITATION SOURCES

In the design of the APS, it is the vertical vibration of the quadrupole magnets, relative to the particle beam passing through the magnets, that is of primary concern. Potential excitation sources that can contribute to the vibration of the magnets include coolant flow through the magnets, energization of the magnet of concern and/or adjacent magnets, and the operation of building equipment (pumps, overhead crane, ventilating equipment and the like). Vibration energy that is not generated within the magnets themselves is transmitted to the magnets via coupling that can involve some or all of the following elements in various combinations: the building support structure, different floor slabs, foundations, equipment mounts, and the magnet support structure.

The following excitation sources, associated with the design and operation of the IPNS facility, were selected for study as being representative of the type of vibration excitation sources and energy transmission paths one has to be concerned with in the design of the APS facility:

- Coolant (water) flow through the beam line magnets (dipole and quadrupoles)
- Energization of the magnets (dipole and quadrupoles) in the beam line
- Operation of RCS ring magnets ("kickers" pulsed at 30 Hz)
- Water pump located on the top of the IPNS monolith
- Ventilating fans (3) on roof of high-bay
- Overhead 10-ton crane

The test program described in Section 4.0 was planned with the objective to provide information on vibration levels, frequency content, energy transmission, and coupling associated with these representative vibration excitation sources.

4.0 TEST DESCRIPTION

Six more-or-less independent tests, each involving seven different measurement positions, were defined as follows:

TEST A - Pump/Floor/Building Coupling

TEST B - Crane/Building/Floor Coupling

TEST C - Pump/Floor/Magnet Coupling

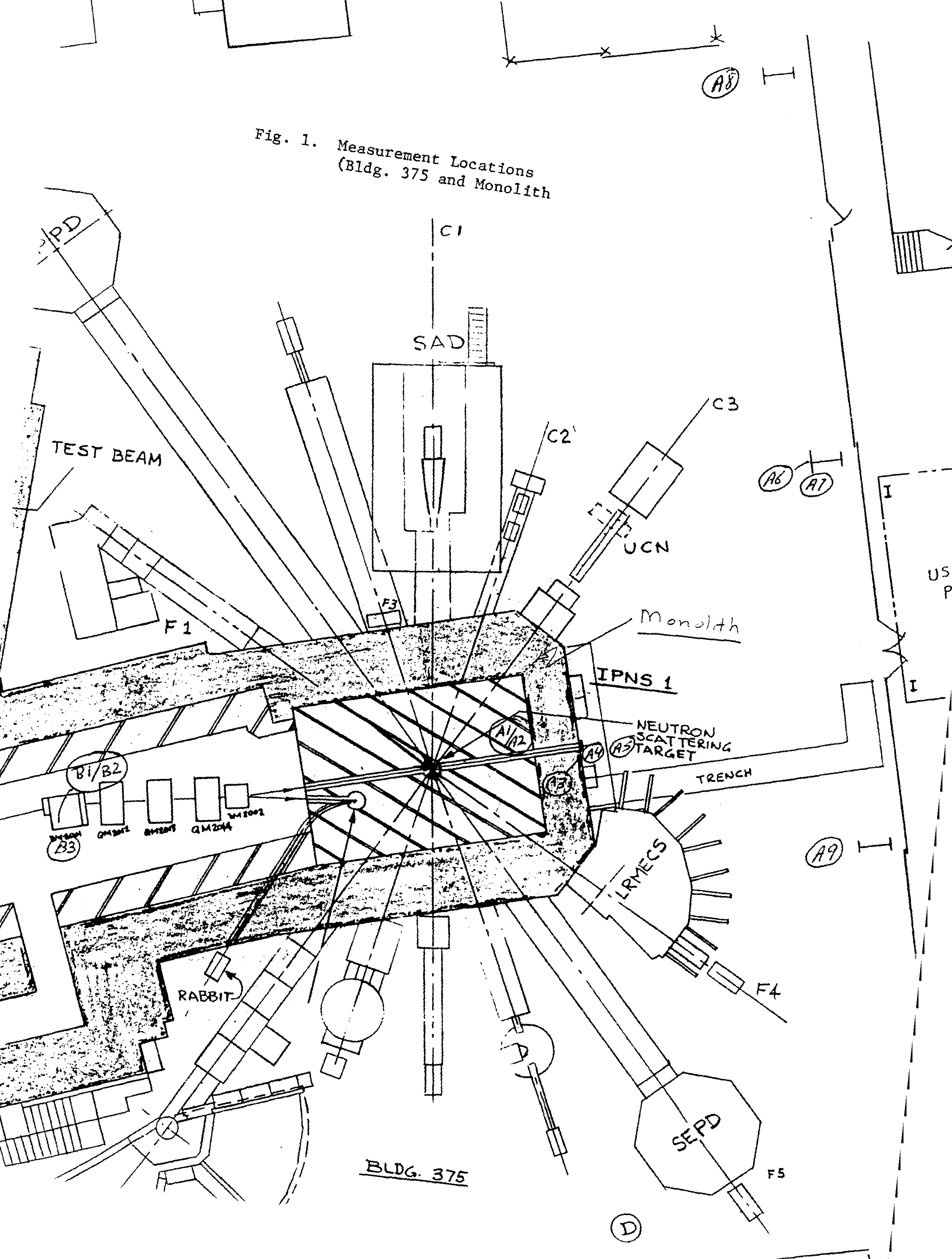
TEST D - Crane/Floor/Magnet Coupling

TEST E - Coolant/Magnet/Floor Coupling

TEST F - Linac/Building/Ground Coupling

The measurement locations for Tests A-E are identified on Figs. 1 and 2 and are described in Table 1. Specific objectives, test conditions, and measurement locations for Tests A-E are given below. The seven measurements specified for each test are made simultaneously to allow for subsequent crosscorrelation of the measured vibration time histories.

Fig. 1. Measurement Locations
(Bldg. 375 and Monolith



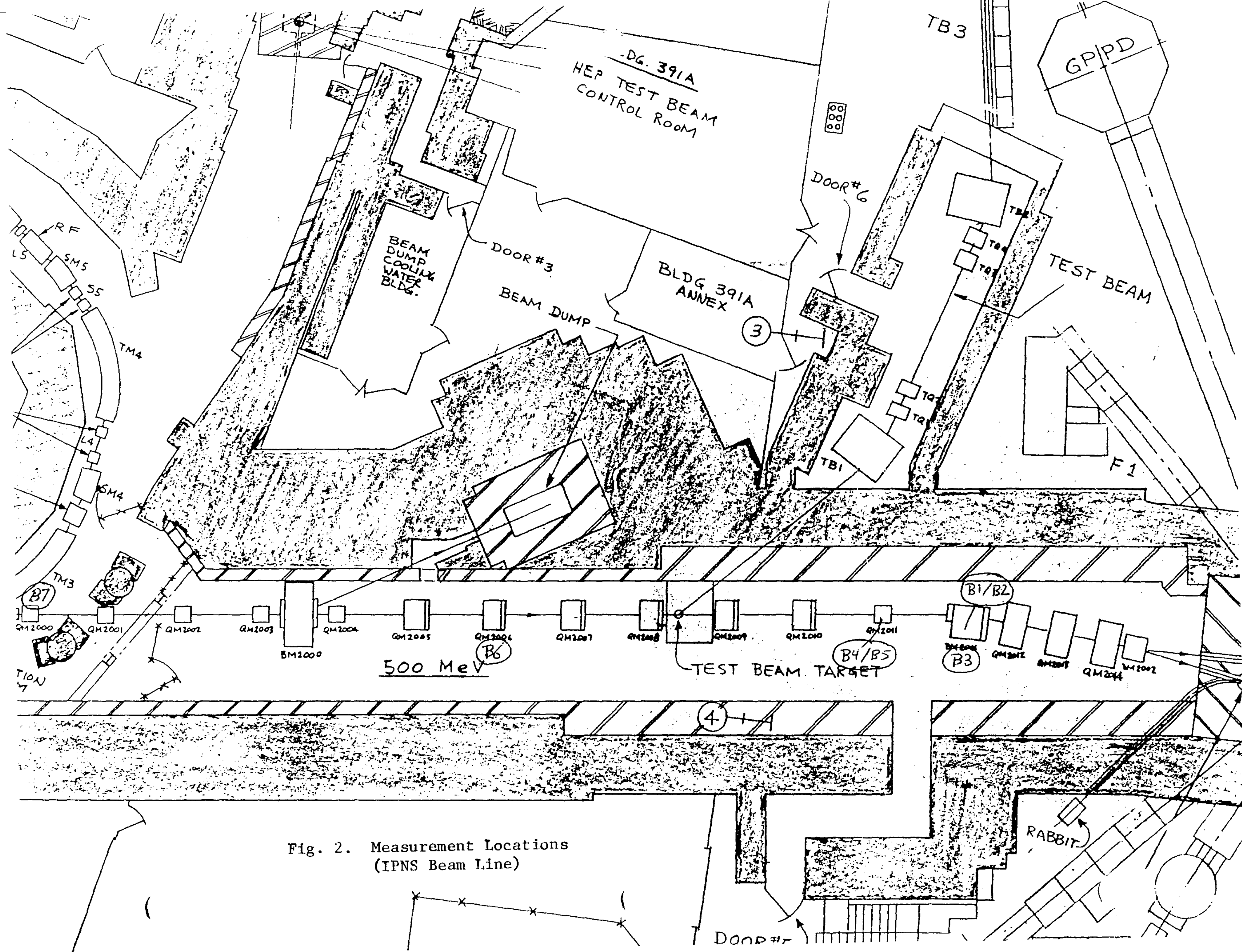


Fig. 2. Measurement Locations
(IPNS Beam Line)

TABLE 1

Measurement Locations/Descriptions -

Location*	Description
A1,A2	Water pump on top of IPNS "monolith" (H, V)**
A3	South wall of monolith (H)
A4	Monolith foundation floor (V)
A5	High-bay floor @ base of monlith (V)
A6	Building I-beam supporting crane rail (H)
A7	High-bay floor @ base of I-beam (V)
A8	High-bay floor - SE end (V)
A9	High-bay floor - SW end (V)
B1,B2	Bending magnet (BM 2001) (H, V)
B3	Floor at base of bending magnet (V)
B4,B5	Quadrupole magnet (QM 2011) (H, V)
B6	Floor at base of QM 2006 (V)
B7	Floor near RCS ring magnets (30 Hz Source) (V)
C1-C3	Linac (TBD)
C4-C6	Ground motion (TBD)
C7	Floor of adjacent bldg. (TBD)

*See Figs. 1 and 2.

**H ≡ horizontal orientation, V ≡ vertical orientation

It should be noted that in carrying out the test plan, the plan had to be modified so as to fit in with and not disrupt the operational plans of the IPNS operators. The test descriptions given below reflect the modifications that were made necessary to fit in with the operation of the IPNS facility. In the "window" available in the IPNS schedule it was only possible to perform Tests A, B, and E. The need for the remaining tests will be evaluated based on the results of the tests performed. They will be rescheduled as required.

4.1 Test A - Pump/Floor/Building Coupling

4.1.1 Objectives

The objective of Test A is to determine the following:

(1) "ambient" vibration levels in IPNS high-bay area (floor, building support structure, monolith) with only auxiliary equipment operating (Bldg. 375 baseline)

(2) effect of operation of pump located on top of monolith on vibration levels measured on the monolith, floor, and building support structure

(3) transmission/attenuation characteristics of pump-induced vibration

4.1.2 Measurement Locations

Measurement positions A1-A7

4.1.3 Test Conditions

(1) IPNS not operating, but RCS ring magnets (strong 30 Hz source) energized - normal building activity - ventilating fans off (baseline)

(2) Same as (1) but with water pump on top of monolith operating (normal operation - low flow)

(3) Same as (1) but with ventilating fans operating

4.1.4 Test Date

March 6, 1987

4.2 Test B - Crane/Building/Floor Coupling

4.2.1 Objectives

The objective of Test B is to determine the following:

(1) effect of operation of overhead crane on vibration levels measured on the monolith, floor, and building support structure

(2) transmission/attenuation of crane-induced vibration

4.2.2 Measurement Locations

Measurement positions A3-A9

4.2.3 Test Conditions

(1) IPNS not operating - normal building activity - ventilating fans on (baseline)

(2) Same as (1) but with crane operating at "East" end of high-bay - ventilating fans on - RCS ring magnets energized

(3) Same as (2) but with crane operating near instrumented column (centered over measurement positions A6/A7)

4.2.4 Test Date

March 6, 1987

4.3 Test C - Pump/Floor/Magnet Coupling

4.3.1 Objectives

The objective of Test C is to determine the following:

(1) effect of operation of the water pump, located on the top of the monolith, on the vibration of the beam line floor and magnets

(2) transmission/attenuation characteristics of the pump-induced vibration

4.3.2 Measurement Locations

Measurement positions B2, B3, B5, A1, A2, A4, and A5

4.3.3 Test Conditions

(1) IPNS not operating - normal building activity - no coolant flow - magnets (beam line and ring) not energized (baseline)

(2) Same as (1) but with pump operating

4.3.4 Test Date

To Be Determined

4.4 Test D - Crane/Floor/Magnet Coupling

4.4.1 Objectives

The objective of Test D is to determine the following:

(1) effect of operation of overhead crane on the vibration of beam line floor and magnets

(2) transmission/attenuation characteristics of crane-induced vibration

4.4.2 Measurement Locations

Measurement positions B2, B3, B5, and A4-A7

4.4.3 Test Conditions

(1) IPNS not operating - normal building activity - no coolant flow - magnets (beam line and ring) not energized (baseline)

(2) Same as (1) but with overhead crane operating

4.4.4 Test Date

To Be Determined

4.5 Test E - Coolant/Magnet/Floor Coupling

4.5.1 Objectives

The test objective is to determine the following:

(1) "ambient" vibration levels of beam line (magnets and floor) without coolant flow and without magnets energized

(2) effect of coolant flow on vibration of magnets

(a) dipole (bend) magnet

(b) quadrupole magnet

(3) effect of magnets being energized on vibration

(a) self-induced

(b) transmitted through floor/supports from operation of adjacent magnet(s)

(4) transmission through floor/supports of 30 Hz source when ring magnets are energized

4.5.2 Measurement Locations

Measurement positions B1-B7

4.5.3 Test Conditions

(1) Magnets not energized, no coolant flow, some auxiliary equipment (vacuum pumps) operating, ring magnets not energized (baseline)

(2) Same as (1) but with coolant flow through magnets

(3) Same as (2) but with dipole (1500 Amp) magnet energized

(4) Same as (2) but with all quadrupole (250 Amp) magnets energized

(5) Same as (2) but with RCS ring magnets energized

4.5.4 Test Date

March 6, 1987

4.6 Test F - Linac/Building/Ground Coupling

4.6.1 Objectives

The test objective is to determine the following:

(1) ambient vibration levels in linac building with and without linac operating

(2) transmission/attenuation in the soil of vibration generated by the linac (via ground motion measurements at various distances from source)

(3) transmission of vibration generated by the linac to nearby building(s)

4.6.2 Measurement Locations

To Be Determined

4.6.3 Test Conditions

(1) Linac shutdown

(2) Linac operating

4.6.4 Test Date

To Be Determined

5.0 INSTRUMENTATION

Accelerometers (PCB Model No. 393C) were used to measure the acceleration response of the experiment hall floor, building support structures, and select IPNS components. Small aluminum pads (3 in. x 3 in. x 1/4 in.) were epoxied to the structure at the designated measurement locations; the accelerometers were fastened to the pads with #10-32 studs. Connections between the accelerometers and signal conditioning amplifiers (PCB Model No. 480D06) were made using 675 ft. lengths of RG-58 coaxial cable on reels which could be unreeled to the required lengths [4].

Accelerations were recorded on a Teac Model MR-30 FM tape recorder operated at a tape speed of 1.87 inches per second. This allowed a frequency response of 0-1.25 KHz [5]. Approximately 5 minutes of data were recorded for each test. Power spectral densities (PSDs) of acceleration, and double integration of accelerations to generate PSDs of displacement, were obtained with a Hewlett-Packard 5451C Fast Fourier Transform Analyzer and plotted together with real-time signals.

6.0 TEST RESULTS

For each test run, acceleration-time signals were measured at each of the seven measurement locations and the data were stored on magnetic tape. Subsequently, the data were processed on the HP Fast Fourier Transform Analyzer. Power spectral density (PSD) plots of acceleration, over the frequency range 5 Hz to 1 kHz, were generated and the rms acceleration computed; the results are given in Appendix A. The acceleration data were double integrated to obtain displacement and power spectral density plots of displacement over the frequency range 10 to 250 Hz. From the displacement power spectral density, rms displacements due to (1) frequency components in the band 5 to 250 Hz, (2) the 30 Hz component alone, and (3) frequency components in the band 10 to 250 Hz with the 30 Hz contribution digitally filtered out, were computed. The results are given in Appendix B; the rationale for processing the data in this manner is given below.

The 30 Hz component is associated with the RCS ring magnets, which are pulsed at a 30 Hz rate. The 30 Hz component is very strong and can be detected throughout the IPNS complex. Therefore, it was felt that it would provide a good "tracer" in studying the transmission and attenuation of vibrations. For this reason the 30 Hz component was isolated in the above described data processing.

Because the 30 Hz component is so strong it tends to dominate the vibration signals when the RCS magnets are on. Also, as discussed above, low frequency vibrations are not a concern in the 7-GeV APS design. For these reasons, and to obtain representative measures of floor and magnet response that could be related to the 7-GeV APS design, rms displacements with frequencies less than 10 Hz and the frequency component at 30 Hz filtered out were computed.

Selected acceleration-time signals are given in Appendix C, together with PSD plots and computed rms acceleration levels.

6.1 Acceleration Data

Frequency content of the vibration signals is most readily determined from the acceleration PSDs. As shown on the acceleration PSDs of Appendix A, for the most part, the signals are made up of discrete frequency components. For example, when the ring magnets, which are pulsed at a 30 Hz rate, are turned on, we see a 30 Hz component on virtually every record. Also, the 233 Hz component can be associated with operation of the water pump on top of the monolith. 60 Hz and multiples of 60 Hz are seen on several records. These components are most likely related to the electrical line frequency. However, it should be noted that they are not generated in the measurement equipment itself as that equipment is battery operated.

There are several discrete frequency components associated with a particular measurement location. As an example, see Tests A and B, Location A_7(V): accelerometer on floor at base of crane rail support column. The two tests were performed independently, at different times. One test (Test A) was designed to investigate the water pump as an excitation source and the other test (Test B) was designed to study the overhead crane. Nevertheless, the results of both tests showed a strong 720 Hz component for all conditions including the baseline. Interestingly, the 720 Hz component does not appear in the measurements made on the support column.

There are several other discrete frequency components, at approximately 600, 660, 840, 860, 920, and 960 Hz, that appear on some of the PSDs. As an example, Test E, Accelerometer B_4(H) on the quadrupole, shows discrete frequency contributions at 600, 660, and 920, in addition to 360 and 960, when the quadrupole magnets were energized. In general, these have not been identified as to their source.

The dipole magnet was known a priori to be "noisy" when energized. The test signals bear this out; see, for example, the high frequency content in the range 590 to 900 Hz, on Accelerometer B_2(V) of Test E when the dipole is energized. These frequencies were evident in the floor measurements as well; see PSDs from Accelerometers B_3(V) and B_6(V) of Test E.

While the frequency content of the vibration signals is of interest and useful in identifying excitation sources, ultimately it is the displacement data, in the frequency range of interest, relative to the acceptance criteria that is of importance to the design and successful operation of the 7-GeV APS as a source of synchrotron radiation. Consequently, in the following we will focus on the rms displacement data in the frequency range 10 to 250 Hz with the 30 Hz contribution from the pulsed ring magnets filtered out.

6.2 Displacement Data: 10 - 250 Hz; 30 Hz Component Filtered Out

6.2.1 Tests A and B

Tests A and B involve measurements made on the experiment hall floor, support structures, and water pump. The measurement locations are described in Table 1 and illustrated in Fig. 1. These two test series will be considered together. RMS displacements from the frequency range 10 to 250 Hz, with the 30 Hz contribution filtered out, are presented in Table 2. In general, the data can be analyzed by studying the rows or columns of numbers given on Table 2 and, in some cases, by comparing results given in specific rows or columns. To aid in discussion of the results we have identified the rows and columns by number and will refer to them in the discussion below.

Column 1 Baseline ("IPNS off; normal building activity") is approximately the same at all measurement locations except on water pump. This indicates some equipment may be operating on top of the monolith and contributing to that signal. The south wall of the monolith (horizontal direction) is the "quietest."

Columns 1 and 2 Operation of water pump increased rms response over baseline at all measurement locations; smallest increase was on monolith wall, largest increase was on building support column.

Columns 1 and 3 With ventilating fans on, rms response is approximately equal to the baseline values except on the building support column where it is greater. This is as expected.

Columns 3 and 4 Conditions are the same and measured response is almost identical where comparisons can be made. Since the tests were performed at different times, the excellent agreement gives confidence in the measurement capabilities and repeatability of results.

Table 2 RMS Displacements from Test Series A and B

Measurement Location (Orientation)	Trans. No.	RMS Displacement (μm) 10-250 Hz (30 Hz Component Filtered Out) Test A1	Test A2	Test A3	Test B1	Test B2	Test B3
Water pump (H)	A1(H)	0.132	3.40	0.134	-	-	-
Water pump (V)	A2(V)	0.209	4.04	0.212	-	-	-
So. wall monolith (H)	A3(H)	0.026	0.046	0.026	0.025	0.029	0.025
Monolith found. floor (V)	A4(V)	0.033	0.036	0.032	0.032	0.044	0.037
Hi-bay floor near mono. (V)	A5(V)	0.035	0.041	0.035	0.034	0.046	0.039
Crane support column (H)	A6(H)	0.032	0.063	0.052	0.052	0.053	0.053
Column base (V)	A7(V)	0.031	0.049	0.030	0.032	0.170	0.068
Hi-bay floor E. end (V)	A8(V)	-	-	-	0.062	0.065	0.049
Hi-bay floor W. end (V)	A9(V)	-	-	-	0.062	0.061	0.080

Test	Description
A1	Baseline (IPNS not operating, normal building activity)
A2	Water pump on, ventilation fans off, crane not operating
A3	Water pump off, ventilation fans on, crane not operating
B1	Water pump off, ventilation fans on, crane not operating, SRM off
B2	Water pump off, ventilation fans on, crane operating over instrumented column
B3	Water pump off, ventilation fans on, crane operating at East end

Column 4 It is interesting that the floor measurements made at the "East" and "West" ends of the high-bay are approximately a factor of two greater than the other floor measurements. The reason for this is not known.

Rows 1 and 2 With water pumps on, rms response measured on the pumps increases by ~ 200 percent over the baseline which is already high.

Row 3 South wall of monolith has lowest response level (~ 0.026 μm). Wall is only sensitive to pump operation. It should be noted that accelerometer is horizontally oriented.

Row 4 Monolith foundation is "very stable." It essentially does not respond to any of the excitation sources investigated. Somewhat surprisingly, highest response (0.044 μm) is associated with operation of crane over instrumented support column.

Row 5 High-bay floor near monolith is also "very stable." For practical purposes, increases in response to excitation sources is negligible. As with monolith foundation, highest response (0.046 μm) is associated with operation of crane over instrumented support column.

Row 6 Building column supporting crane rail responds to all excitation sources studied. Surprisingly, crane oepration does not affect response. The increase over baseline seems to be attributable to operation of the ventilating fans.

Row 7 Building column base responds to the pump and crane operation but not to the ventilation fans; response to crane operation is relatively large.

Rows 4 and 5 Interestingly, the response of the monolith foundation floor is almost identical to the response of the high-bay floor near the monolith despite the facts that the monolith foundation is significantly thicker (~ 3 ft vs. ~ 9 in.) and much more heavily loaded than the high-bay floor and that the two floors are not connected.

Rows 5, 8, and 9 The floor response at the East and West ends of the experiment hall is greater than the floor response near the monolith.

6.2.2 Test E

Test E involved measurements made on the beam line magnets and floor in the vicinity of the magnet support structures. The measurement locations are described in Table 1 and illustrated in Fig. 2. RMS displacements from the frequency range 10 to 250 Hz, with the 30 Hz contribution filtered out, are presented in Table 3, together with a single set of data from the frequency range 5 to 250 Mz with the RMS energized. As above, row and column numbers related to the data in Table 3 will be used as an aid in discussing the results.

Rows 1 and 2 Coolant flow has a negligible effect on bending magnet (BM) response; rms displacements increased only 0.002 and 0.006 μm in horizontal (H) and vertical (V) directions, respectively. Energization of the quadrupole magnets (QMs) also had no effect on BM response.

Row 3 Coolant flow and energization of the QMs had no effect on floor response at the base on the BM support. When the BM was energized, the floor response at the base of the BM doubled (0.023 to 0.044 μm).

Rows 4 and 5 Coolant flow causes a measurable increase (~ 0.019 μm) in QM response. Energization of the BM did not have a large effect on QM response. Energization of the QMs had a significant effect on the response of the QMs; response increases by a factor of 3.

Row 6 The three excitation sources (coolant flow, BM energized, and QMs energized) have no effect on motion of floor midway between

Table 3 RMS Displacements from Test Series E

Measurement Location (Orientation)	Trans. No.	RMS Displacement (μm) 10-250 Hz (30 Hz Component Filtered Out) Test E5	Test E2	Test E3	Test E4	5-250 Hz Test E1
Bending magnet (H)	B1(H)	0.022	0.025	*	0.023	0.193
Bending magnet (V)	B2(V)	0.047	0.053	*	0.052	0.151
Floor at base of BM (V)	B3(V)	0.024	0.023	0.044	0.023	0.106
Quadrupole magnet (H)	B4(H)	0.026	0.045	0.063	0.137	0.302
Quadrupole magnet (V)	B5(V)	0.036	0.055	0.062	0.115	0.383
Floor midway to SRM (V)	B6(V)	0.026	0.027	0.027	0.027	0.085
Floor near SRM (V)	B7(V)	0.053	0.044	0.043	0.042	1.021

Test	Description
E1	Coolant flow on, RMs energized (30 Hz source)
E2	Coolant flow on, magnets not energized
E3	Coolant flow on, BM energized
E4	Coolant flow on, QMs energized
E5	Baseline (coolant flow off, no magnets energized)

*Signal lost in noise - low gain was required to not saturate electronics at high frequencies (> 250 Hz)

BM and SRM; the response remains equal to the baseline. With the exception of the effect of energization of the BM on the floor motion at the base of the BM, the response at the "midway location" is essentially the same as the response at the "BM base location."

Row 7 Even with the ring magnets (RMs) off, the floor response near the RMs is in all cases greater than the corresponding response at other floor locations. It is surprising that the baseline response is the greatest.

Column 1 With the exception of the location near the RMs, the baseline floor response is ~ 0.026 μm. The fact that the vertical vibration response of the BM (0.047 μm) and QM (0.036 μm) is measurably greater implies dynamic amplification by the magnet support structure.

Column 5 With the RMs energized, the response at all measurement locations (frequency range 5 to 250 Hz) is significant, i.e., > 0.1 μm, with one exception. As to be expected, the floor response near the RMs is the greatest (~ 1 μm). At the other two floor locations the response is ~ 0.1 μm. However, the vertical response measured on the BM and QM are greater, 0.15 and 0.38 μm, respectively. Again, this is indicative of dynamic amplification of the floor motion via the magnet support structures.

6.3 Displacement Data; 30 Hz Component

As discussed above, the 30 Hz component was isolated in hopes of using it as a tracer to study propagation/attenuation characteristics. The rms displacement associated with the 30-Hz component of the vibration was computed. The results are given on the PSD plots in Appendix B and in tabular form in Tables 4 and 5.

Floor motion near the RCS ring magnets, Accelerometer B7(V), can be considered as the excitation source; as given in Table 4, the rms displacement

Table 4 RMS Displacement Associated with 30 Hz Component

Measurement Location (Orientation)	Trans. No.	RMS Displacement (μm) Test A1	Test A2	Test A3	Test B1	Test B2	Test E1
Water pump (H)	A1(H)	0.128	0.602	0.131	-	-	-
Water pump (V)	A2(V)	0.069	0.503	0.067	-	-	-
So. wall monolith (H)	A3(H)	0.067	0.042	0.066	0.060	0.062	-
Monolith found. floor (V)	A4(V)	0.058	0.034	0.058	0.054	0.057	-
Hi-bay floor near mono. (V)	A5(V)	0.055	0.031	0.055	0.051	0.055	-
Crane support column (H)	A6(H)	0.026	0.069	0.037	0.037	0.060	-
Column base (V)	A7(V)	0.064	0.027	0.063	0.063	0.059	-
Hi-bay floor E. end (V)	A8(V)	-	-	-	0.059	0.034	-
Hi-bay floor W. end (V)	A9(V)	-	-	-	0.138	0.157	-
Floor at base of BM (V)	B3(V)	-	-	-	-	-	0.091
Floor midway to SRM (V)	B6(V)	-	-	-	-	-	0.048
Floor near SRM (V)	B7(V)	-	-	-	-	-	0.907

See Tables 2 and 3 for description of various tests

Table 5 RMS Displacements Associated with 30 Hz Component: Test E1*

Measurement Location (Orientation)	Trans. No.	RMS Displ. (μm)
Bending Magnet (H)	B1(H)	0.013
Bending Magnet (V)	B2(V)	0.116
Floor at base of BM (V)	B3(V)	0.091
Quadrupole magnet (H)	B4(H)	0.068
Quadrupole magnet (V)	B5(V)	0.361
Floor midway to SRM (V)	B6(V)	0.048
Floor near SRM (V)	B7(V)	0.907

*Coolant flow on, RMs energized (30 Hz source), Bending and Quadrupole magnets not energized.

at 30 Hz is relatively high (0.91 μm) at that location. Ideally, we would like to be able to generate an attenuation curve with distance from the source similar to that developed by Huke [3] and reproduced in Fig. 3.

The 30-Hz component was detected throughout the facility and, in general, the signal was reduced in strength from what it was at the source. Nevertheless, as a study of the data indicates, it is not possible to develop a logical attenuation pattern. In most cases the response level is in the range 0.05 to 0.07 μm. The displacements measured on the pump were especially high indicating that there may be a 30-Hz component associated with operation of the pump or other equipment operating in the vicinity of the pump on the monolith.

In Table 5, rms displacements associated with the 30 Hz component are given from measurement made on the magnets and floor of the beam line. The highest response (0.91 μm) is at the location of Accelerometer B7(V) near the pulsed RCS ring magnets. The floor response decreases with distance from the "source," but not monotonically; the floor response approximately midway between the bending magnet and RCS is 0.048 μm (Accelerometer B6(V)) while the response at the bending magnet is 0.091 μm (Accelerometer B3(V)). It is interesting to note that the high-bay floor response to the 30 Hz pulse (see Table 4) is typically greater than the floor response measured by Accelerometer B6(V). Horizontal motion of the dipole magnet (0.013 μm) and quadrupole magnet (0.068 μm) is relatively small compared to the vertical motions of 0.116 μm and 0.361 μm, respectively.

The fact that the vertical amplitudes of the magnet vibration are significantly greater than the floor motion once again implies dynamic amplification in the magnet/support assembly. Huke [3] also reports an amplification. As discussed earlier, in his study, the 20.5 Hz vibration

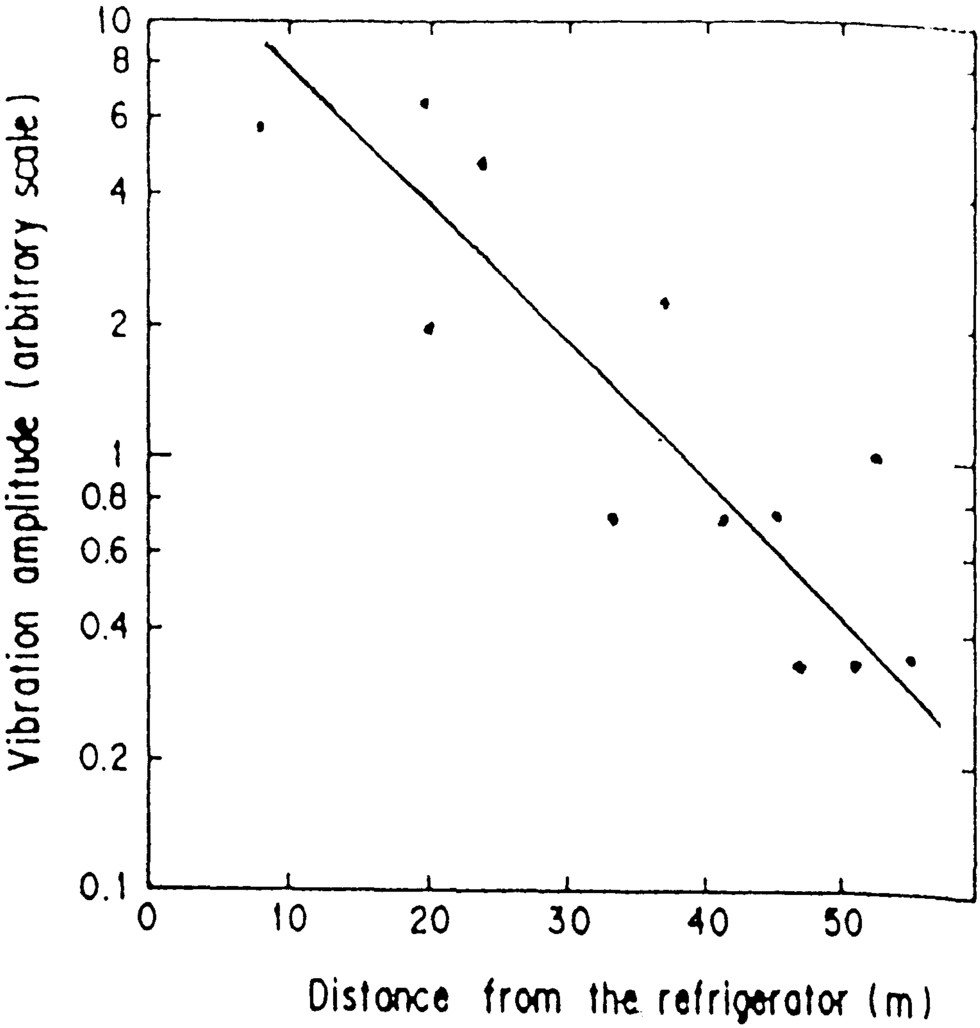


Fig. 3. Attenuation curve of the 24.7 Hz component in the 2.5-GeV light source building [3]

component, with a maximum amplitude of 0.08 μm, excited an SR axis vibration of 2.0 μm.

6.4 Acceleration-Time Signals

Representative acceleration-time signals, corresponding to high-bay floor response and crane support column motion associated with operation of the overhead crane, are given in Appendix C. The intermittent motion associated with crane operation is apparent on the time signal from Test B2, Accelerometer A6(H) on the crane support column.

It is also of interest to note that the floor accelerometers sensed the operation of a dumpster in the vicinity of the high-bay. The transient is shown in the three floor response time signals from Test B3. At least in one case, Test B3, Accelerometer A8(V), the transient appears as high frequency (700-1000 Hz) noise in the acceleration PSD.

6.5 Displacement-Time Signals

Displacement-time signals corresponding to horizontal and vertical vibration of both the quadrupole and bending magnets are given in Appendix D. The results are given for the following three conditions: Baseline (coolant flow off, no magnets energized); Coolant flow on, magnets not energized; Coolant flow on, QMs energized. The rms values are for the frequency range 5 to 100 Hz. Therefore, since a significant amount of energy is contained in the low frequency range, the values are larger than those given in Table E which start at 10 Hz.

7.0 EXPERIMENT HALL DESIGN FEATURES

The design features of the IPNS experiment hall (ANL site Bldg. 375) that are pertinent to the subject vibration study are reviewed below and, as possible, are compared with the proposed 7-GeV APS experiment hall.

As illustrated in Fig. 1, the IPNS neutron scattering target is housed in the "monolith" which consists of steel and concrete shielding, the concrete shielding being in the form of removable concrete blocks. As shown in Fig. 4, the monolith rests on its own foundation which is separate from the experiment hall floor slab. The thickness of the monolith foundation is 3 feet. The foundation rests on approximately 8" of compacted granular fill on top of the soil. The experiment hall floor slab is ~ 9 in. thick resting on ~ 10 in. of compacted granular fill. The width of the monolith foundation is ~ 42 feet. The total width of the experiment hall is 164 feet.

Columns supporting the overhead 10-ton bridge crane are essentially supported directly off of the floor slab as illustrated in Fig. 4 and the detail in Fig. 5. The height to the bottom of the roof trusses is 38'-9".

It is of interest to compare the IPNS foundation and building design with that of the 7-GeV APS. A cross-section through the APS experiment hall is given in Fig. 6. As shown in Fig. 6, the storage ring foundation is two feet thick and is separate from the experiment hall floor slab which is 1 foot thick; both foundation and floor slab are on 6 in. compacted granular fill. The APS hall is an annular structure 91 feet wide by 3472 ft in circumference at the storage ring center line. The clear height from the experiment hall floor to the underside of the truss is 24.5 feet. Two 10-ton cranes span the experiment hall area. The columns are supported on individual caissons (2 ft-6 in. in diameter, extending 40 ft below finished grade). Elastomeric bearing pads are provided beneath the base plates of the columns. The storage ring foundation and experiment hall floor slab are isolated from the building foundation by an air gap.

Relative to vibration effects, there are similarities as well as differences between the IPNS and 7-GeV APS. To begin with, the 30 Hz pulsed

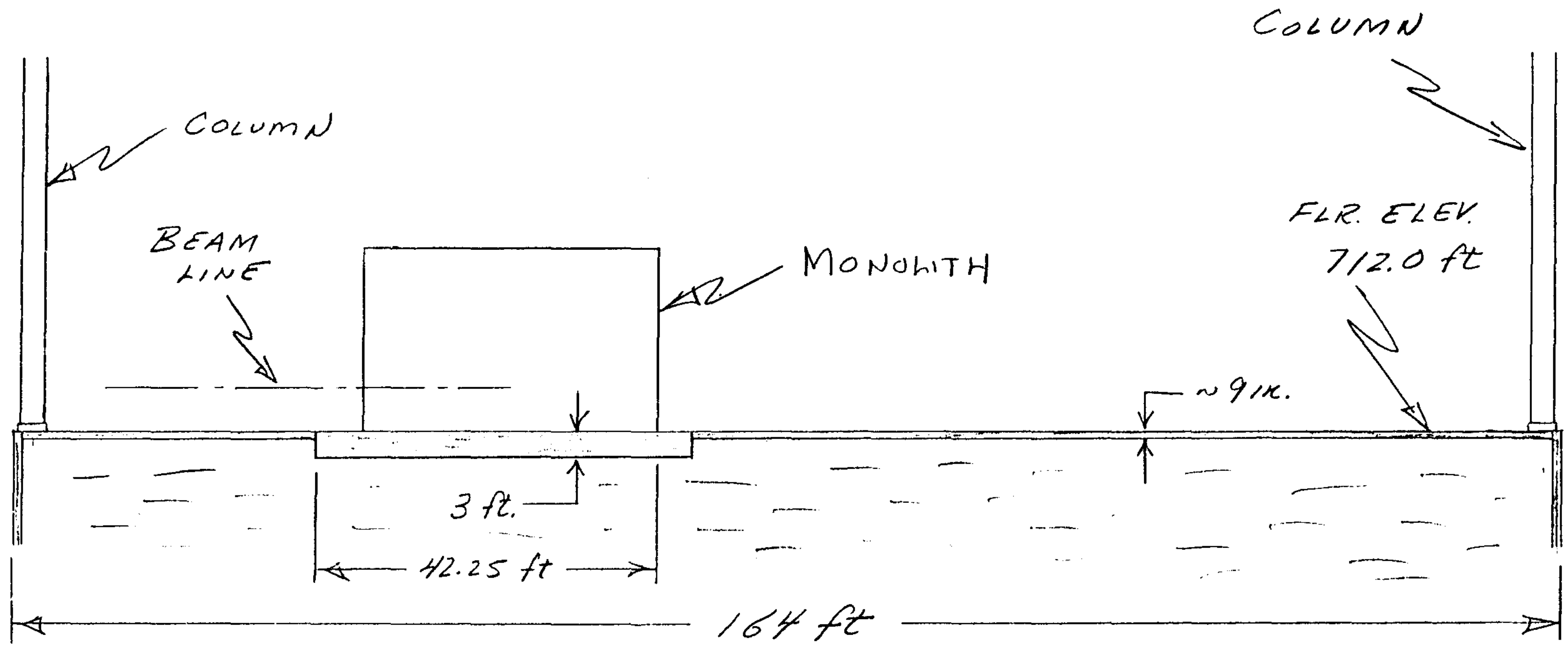


Fig. 4. Cross-section through IPNS-I Bldg. 375

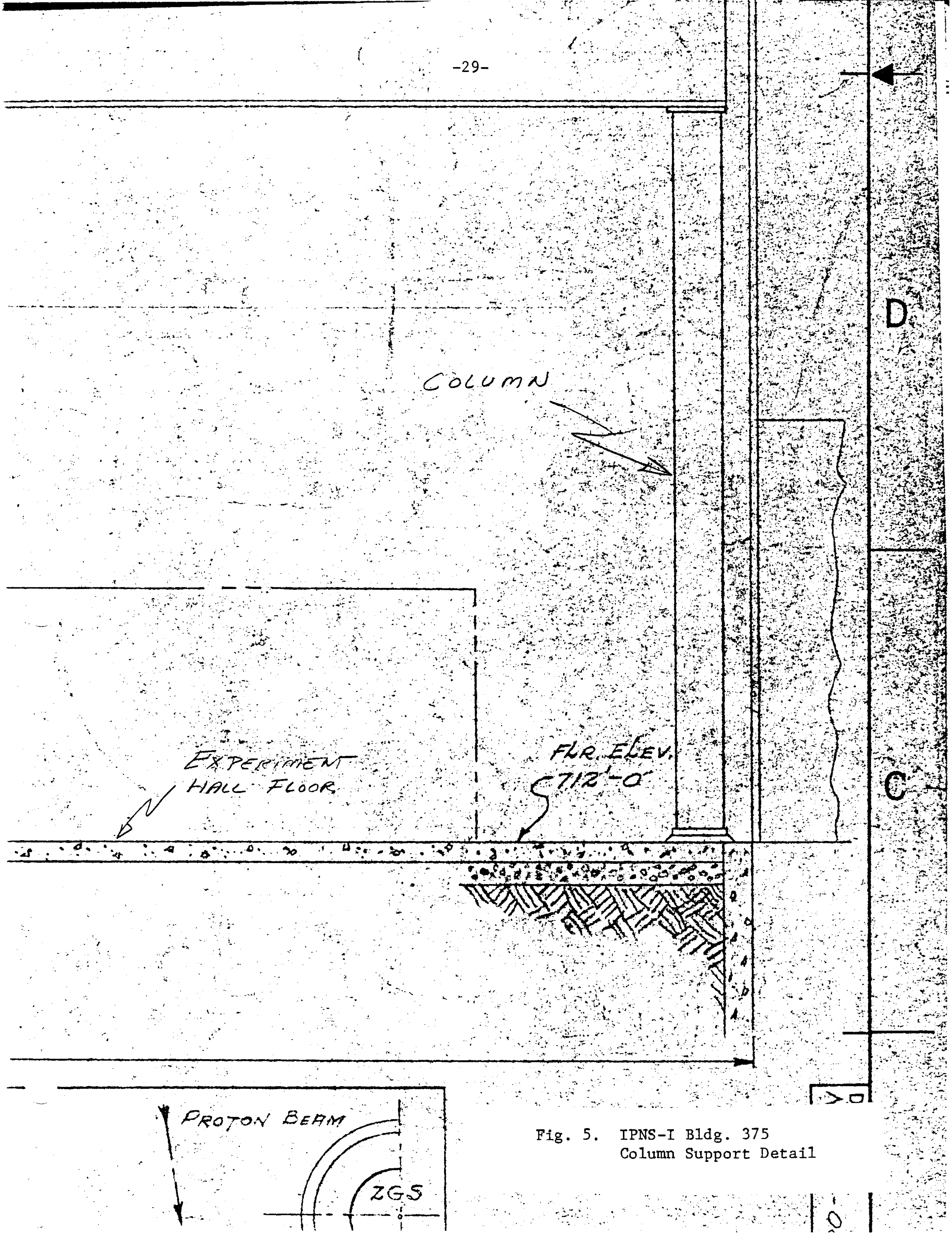


Fig. 5. IPNS-I Bldg. 375
Column Support Detail

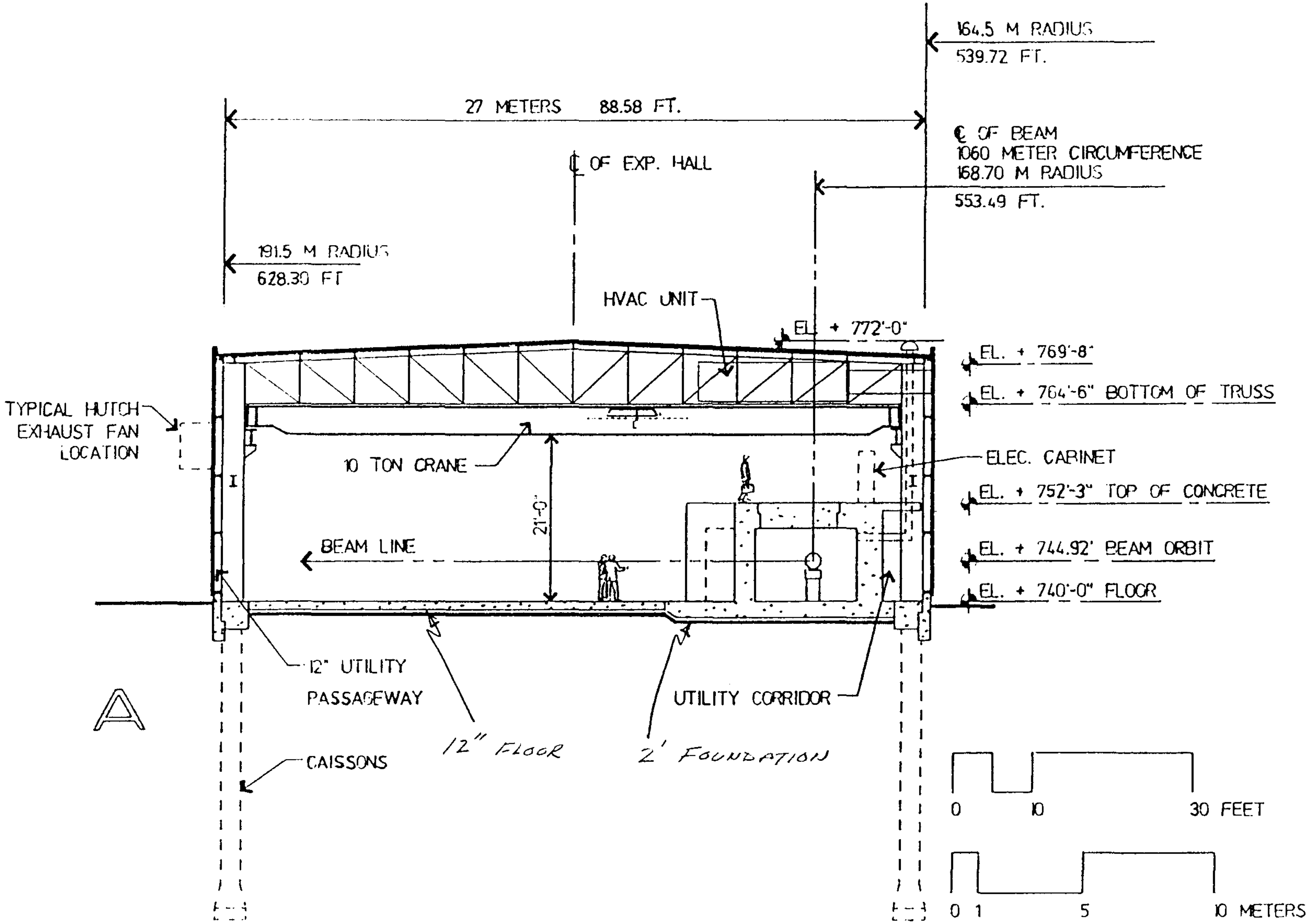


Fig. 6. Cross-section through 7-GeV APS Experiment Hall

ring magnets are unique to the IPNS; there are no pulsed magnets in the APS. There is similarity in the fact that the "machine foundation" is separate from and thicker than the experiment hall floor. The IPNS monolith foundation is 3 feet thick compared to the APS storage ring foundation thickness of 2 feet, and more heavily loaded. The IPNS experiment hall floor is ~ 9 in. thick compared to the APS experiment hall floor thickness of 12 in. In the IPNS the experiment hall floor is not isolated from the building crane/support columns and building structure as it is, by an air gap, in the APS. The experiment hall floor elevation of the IPNS is 712.0 ft; the elevation of the 7-GeV APS experiment hall floor will be 740.0 ft.

8.0 CONCLUDING REMARKS

The vibration survey of the IPNS facility has provided useful insights relative to the amplitude, frequency content, and coupling of vibration in an accelerator facility. The results demonstrated the following:

(1) A strong excitation source such as the ring magnets pulsed at 30 Hz will excite significant vibration levels throughout the facility as shown by the data in Tables 4 and 5. Such excitation sources must be avoided or vibration isolation provided.

(2) A thicker and separate foundation for the machine (in the case of the IPNS, the monolith) does not seem to provide vibration isolation. Floor response on either side of the expansion joint between machine foundation and experiment hall floor was the same.

(3) The magnet/support structure provides dynamic amplification of the floor motion as vertical vibration of the instrumented magnets is greater than the vertical motion of the floor with the magnets in a non-operating mode (no coolant flow and not energized).

(4) The operation of the overhead crane does not have a large effect on vibration response of the floor or column support structure even though in the IPNS facility no attempt was made to isolate the crane support column from the floor structure.

(5) In general, it was not possible to assign vibration sources to the various discrete frequencies observed in the frequency spectra; the water pump, with a characteristic frequency of 233 Hz, was one exception.

(6) Neglecting measurements made on the water pump, in the frequency range studied, viz., 10 to 250 Hz, with the 30 Hz component filtered out, the rms vibration levels ranged from approximately 0.025 μm to 0.070 μm. It should be noted that the peak amplitude will range from 1.414 (if the signal is sinusoidal) to ~ 3 (if the signal is random) times the rms value. Huke [3] in his vibration study of the 2.5-GeV storage ring at KEK, reports maximum amplitudes associated with various discrete frequency components; values reported range from 0.002 to 0.081 μm.

(7) Using the dominant 30 Hz component as a "tracer" it was not possible to develop an attenuation curve that monotonically decreases with distance from the source as one might intuitively expect it to and as found by Huke [3] and illustrated in Fig. 3.

(8) Coolant flow has a measurable but not significant effect on magnet vibration

(9) Energizing the quadrupole magnets resulted in a considerable increase (factor greater than 2) in vibration level, with measured rms amplitudes of 0.137 μm and 0.115 μm in the horizontal and vertical directions, respectively.

In general, the measured vibration levels were relatively low for a facility that was not designed to mitigate vibration. With regard to the 7-GeV APS, the results of the subject study call attention to the importance of dynamic amplification by the magnet/support structure and the effect energizing the magnets can have on vibration response. This requires that careful attention be paid to the design of the magnet support structure. Also, it appears that operation of the overhead crane may not be of major concern as a vibration source. This is especially so in light of the fact that in the 7-GeV APS design, the crane support columns are mounted on caissons isolated from the experiment hall floor slab and storage ring foundation, with further isolation provided by elastomeric pads at the base of the columns.

REFERENCES

1. Chou, W., "Static and Dynamic Emittance Growth in a Storage Ring," ANL Report, Light Source Note LS-87 (1987).

2. Katsura, T., Kamiya, Y., Haga, K., Mitsuhashi, T., and Hettel, R. O., KEK-Preprint 86-46-August, National Laboratory for High Energy Physics.

3. Huke, K., "Correlation between the Movement of the Light Source Building and the Vibration of the Synchrotron Radiation Axis," Japanese J. Appl. Physics, 26 (2): 285-288 (1987).

4. Jendrzejczyk, J. A., and Smith, R. K., "Evaluation of Effects of Cable Length on Accelerometer Response", ANL Report, Light Source Note LS-80 (1987).

5. Jendrzejczyk, J. A., and Smith, R. K., "Evaluation of Amplitude and Frequency Response Characteristics of the Teac Model MR-30 Tape Recorder", ANL Report, Light Source Note LS-81 (1987).

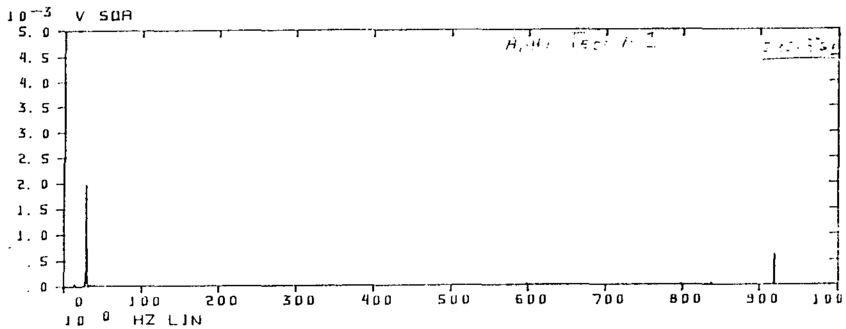
APPENDIX A

Test Series A, B, and E

Acceleration PSDs and RMS values - Frequency range 5 to 1,000 Hz

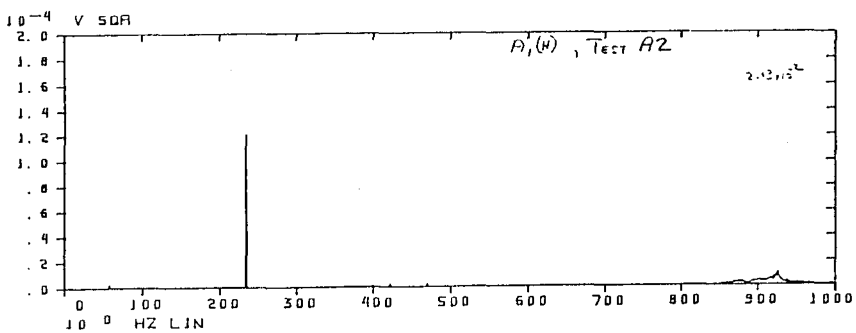
CONDITIONS

G_{RMS}



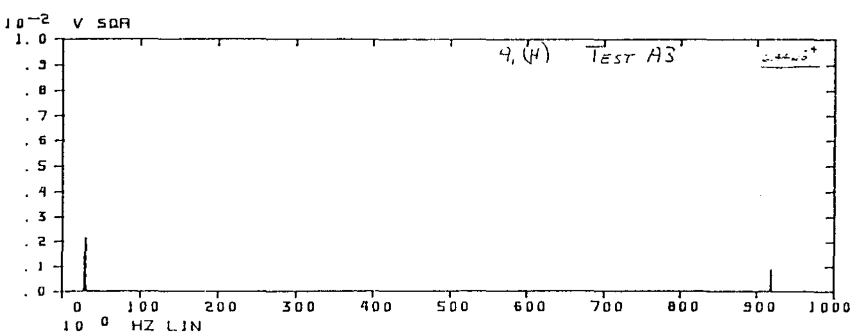
5.85×10^{-4}

1) IPNS Not Operating (Background)
2) Vent. Fans Off



2.13×10^{-2}

1) IPNS Not Operating
2) Pump Operating (Normal Operating Flow)
3) Vent. Fans Off

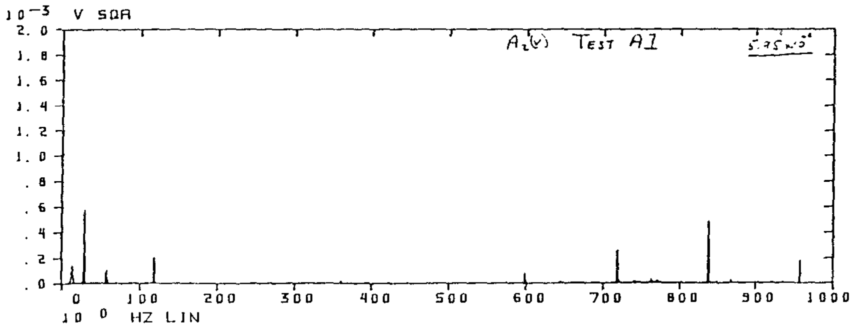


6.44×10^{-4}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Acc. A_1(H) On Pump

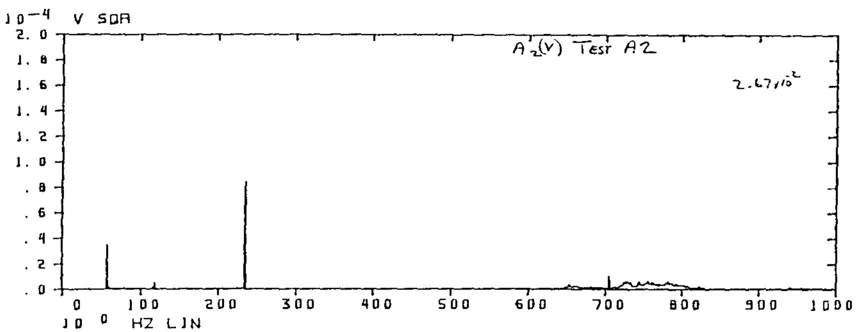
CONDITIONS



G_{RMS}

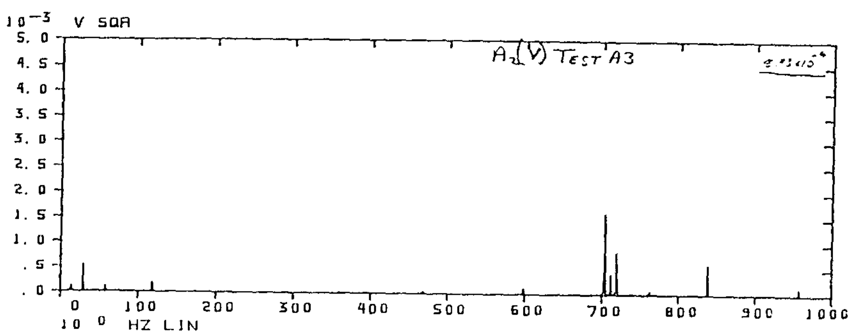
5.95×10^{-4}

1) IPNS Not Operating (Background)
2) Vent. Fans Off



2.67×10^{-2}

1) IPNS Not Operating
2) Pump Operating (Normal Operating Flow)
3) Vent. Fans Off

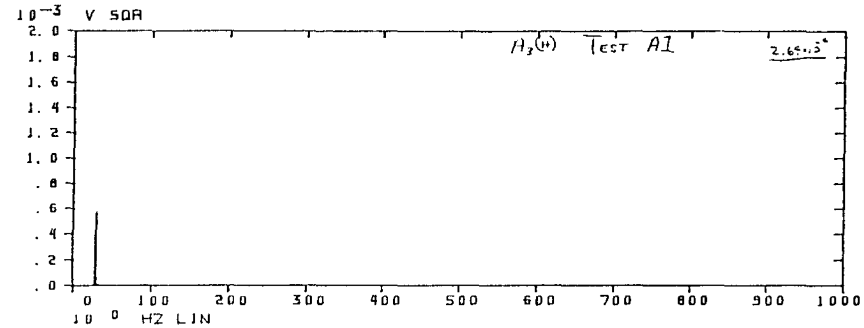


8.93×10^{-4}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Acc. A_2(V) On Pump

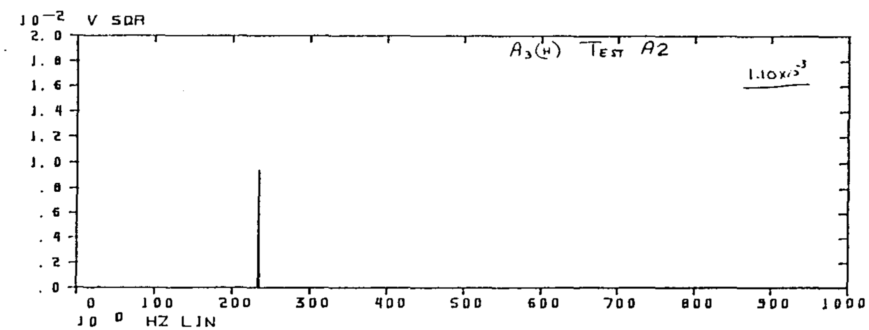
CONDITIONS



G_{RMS}

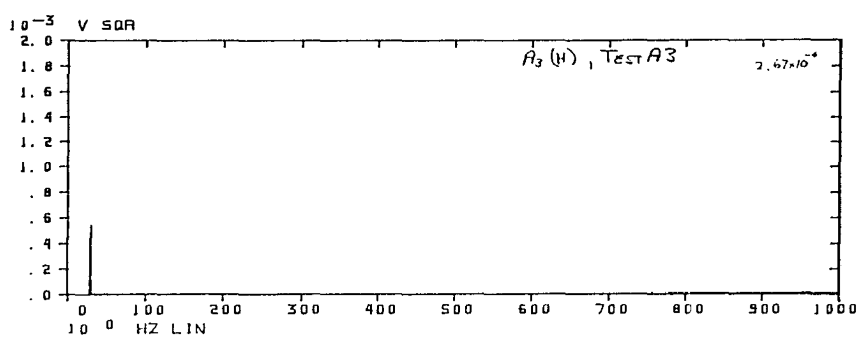
2.64×10^{-4}

1) IPNS Not Operating (Background)
2) Vent. Fans Off



1.10×10^{-3}

1) IPNS Not Operating
2) Pump Operating (Normal Operating Flow)
3) Vent. Fans Off



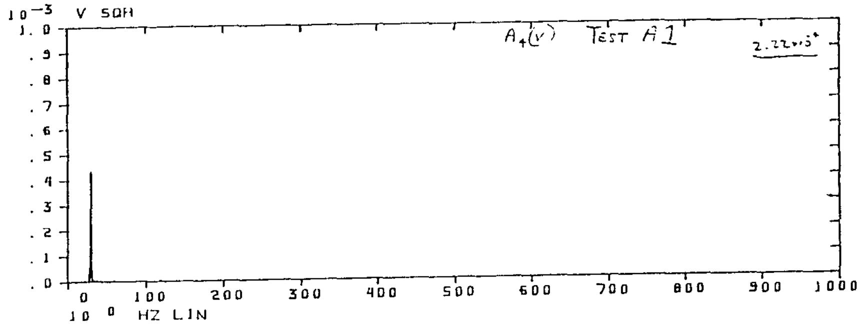
2.67×10^{-4}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Acc. A_3(H) On South Wall of Monolith

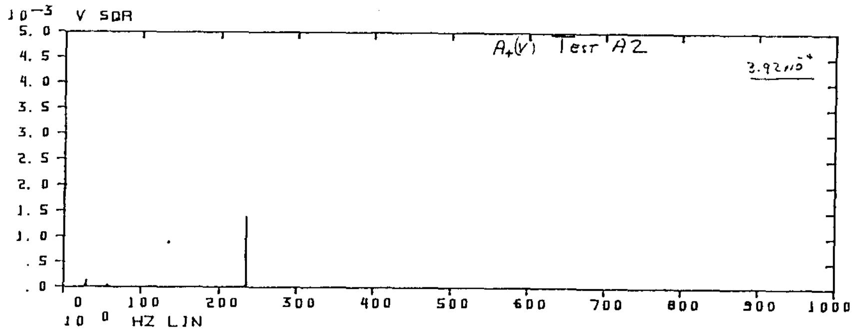
CONDITIONS

G_{RMS}



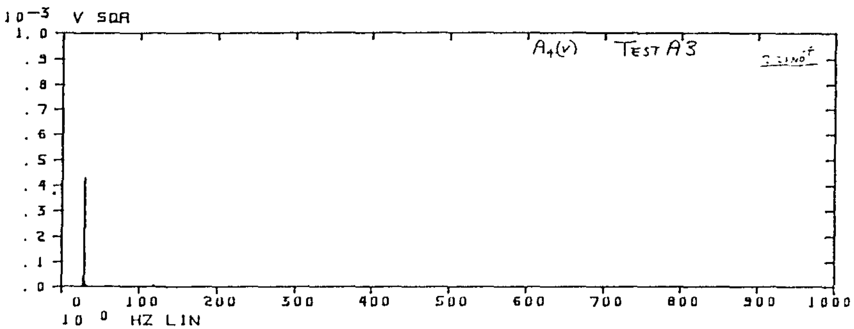
2.22×10^{-4}

1) IPNS Not Operating (Background)
2) Vent. Fans Off



3.92×10^{-4}

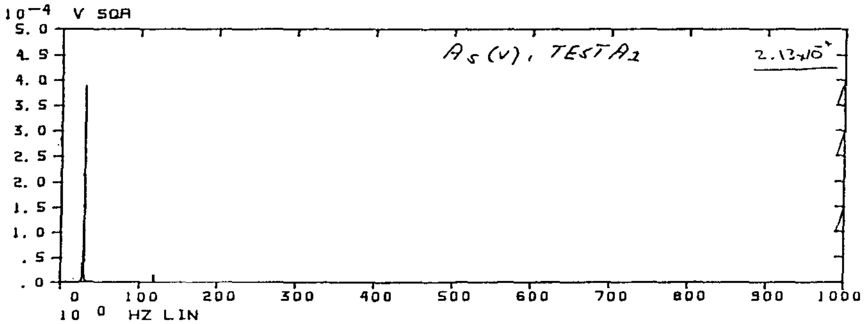
1) IPNS Not Operating
2) Pump Operating (Normal Operating Flow)
3) Vent. Fans Off



2.21×10^{-4}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Acc. A_4(V) (Monolith Foundation Floor

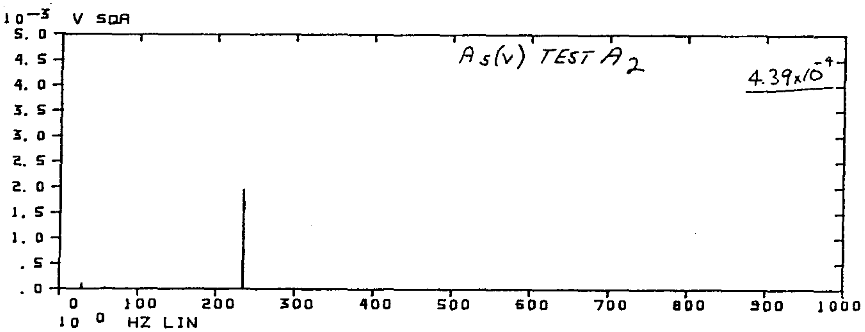


CONDITIONS

G_{RMS}

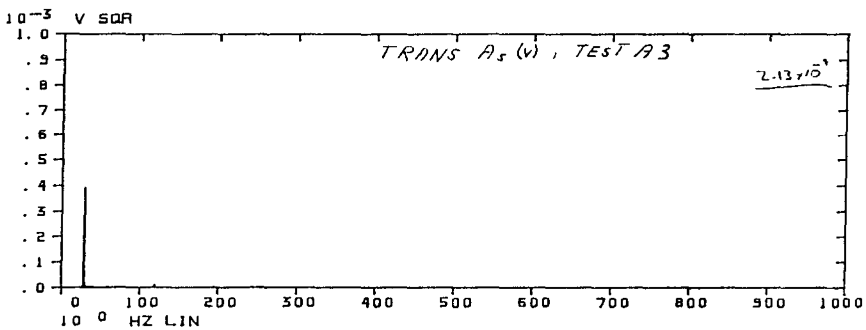
2.13×10^{-4}

1) IPNS Not Operating (Background)
2) Vent. Fans Off



4.39×10^{-4}

1) IPNS Not Operating
2) Pump Operating (Normal Operating Flow)
3) Vent. Fans Off

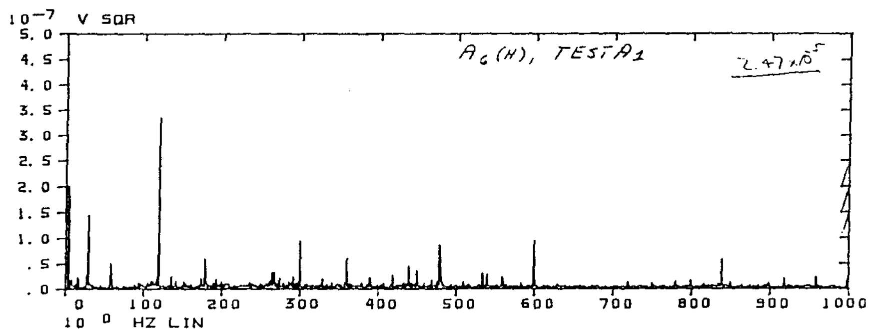


2.13×10^{-4}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Acc. A_5(V) On High-Bay Floor, Near A_4(V)

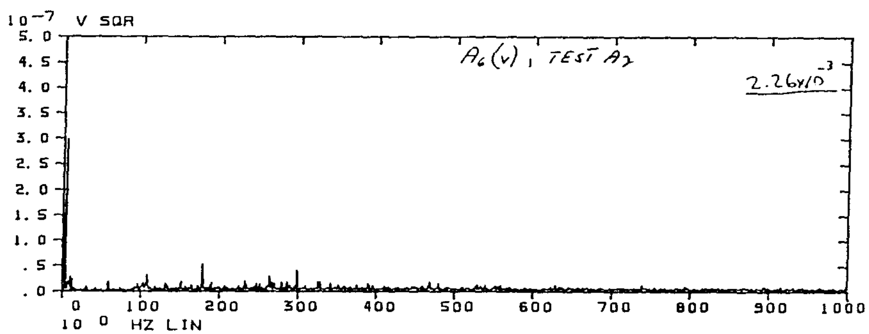
CONDITIONS



G_{RMS}

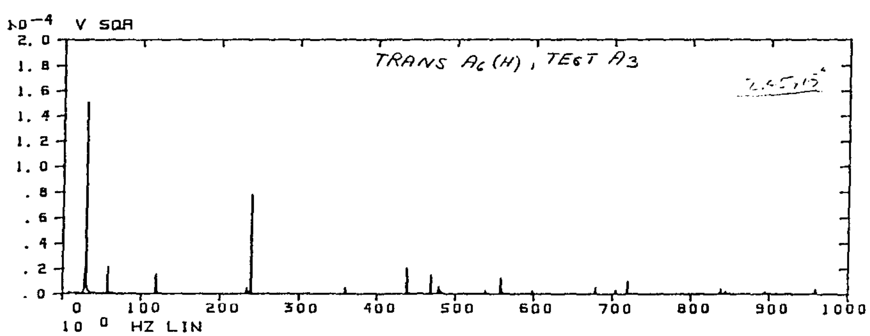
2.47×10^{-5}

1) IPNS Not Operating (Background)
2) Vent. Fans Off



2.26×10^{-3}

1) IPNS Not Operating
2) Pump Operating (Normal Operating Flow)
3) Vent. Fans Off

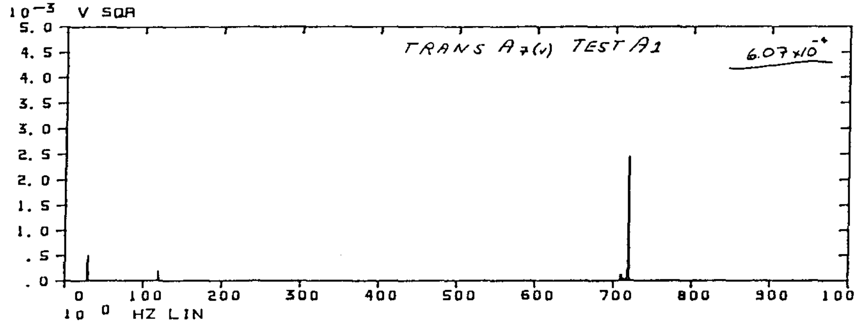


2.45×10^{-4}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Acc. A_6(H) On "I" Beam Supporting Crane Rail (Near A_7)

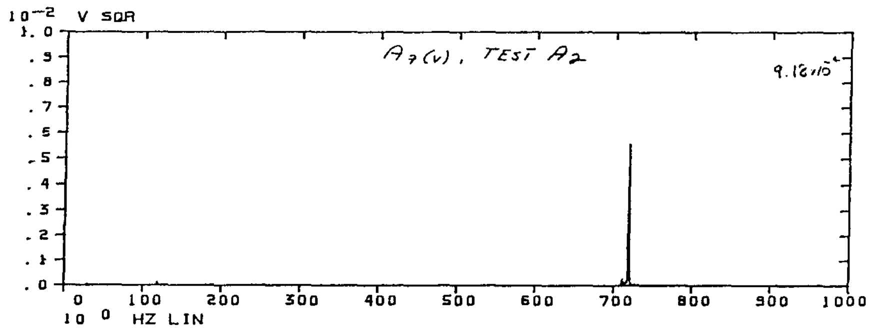
CONDITIONS



G_{RMS}

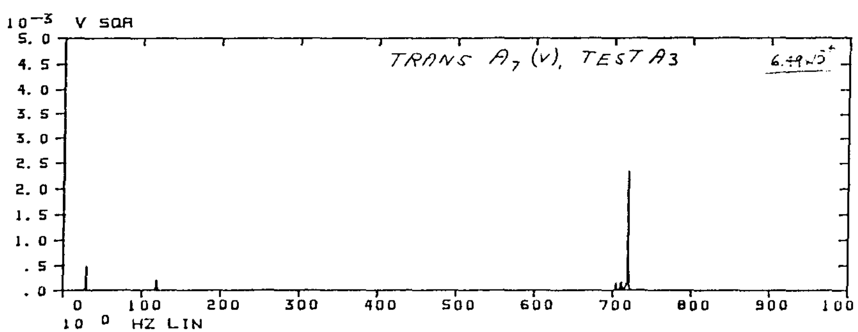
6.07×10^{-4}

1) IPNS Not Operating (Background)
2) Vent. Fans Off



9.18×10^{-4}

1) IPNS Not Operating
2) Pump Operating (Normal Operating Flow)
3) Vent. Fans Off



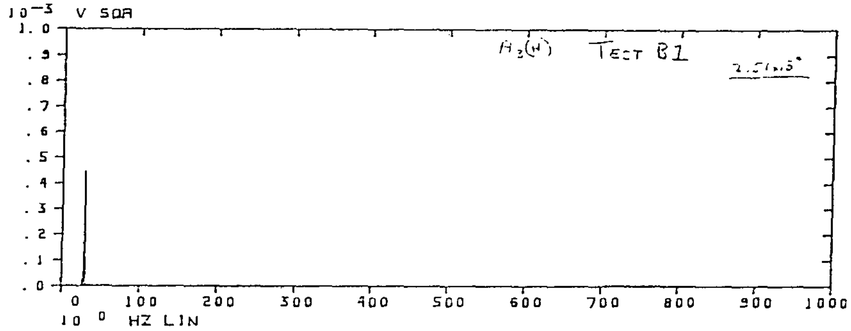
6.49×10^{-4}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Acc. A_7(V) On High-Bay Floor at Base of Crane "I" Beam

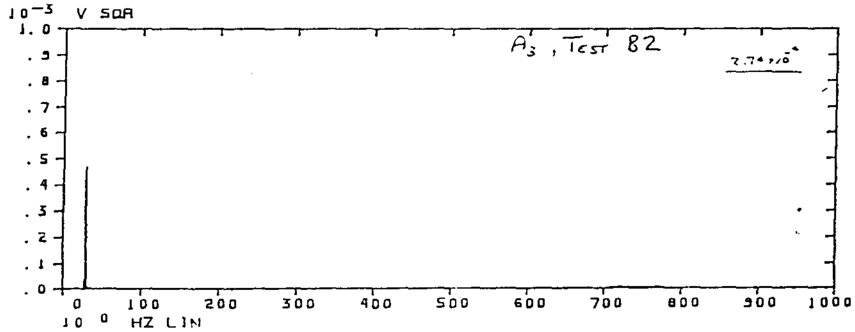
CONDITIONS

G_{RMS}



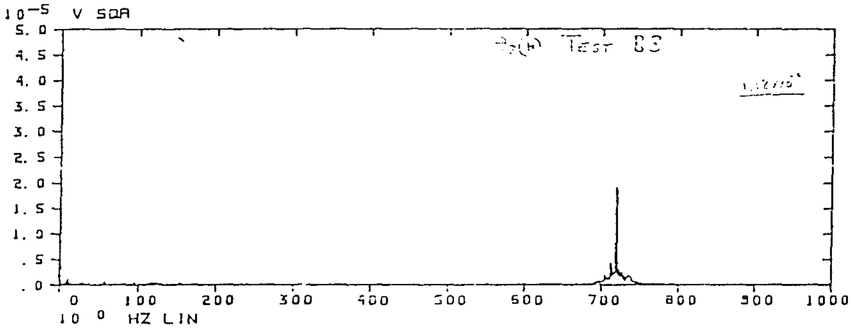
2.51×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On



2.74×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered over A_6,A_7 (Instrumented "I" Beam)
4) 30 Hz On



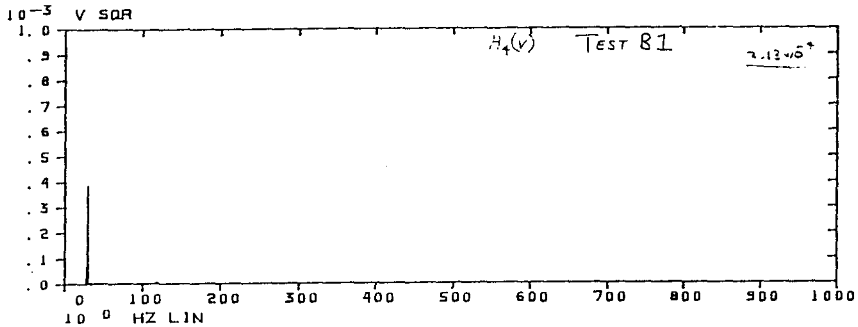
1.18×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operating
4) 30 Hz Off

Test B, Acc. A_3(H) On South Wall of Monolith

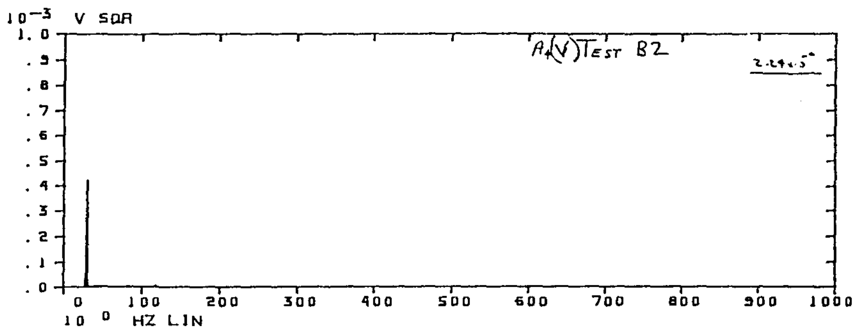
CONDITIONS

G_{RMS}



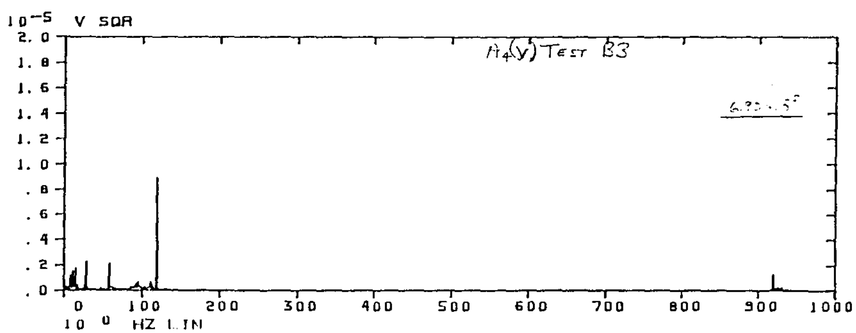
2.13×10^{-3}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On



2.24×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered over A_6, A_7 (Instrumented "I" Beam)
4) 30 Hz On



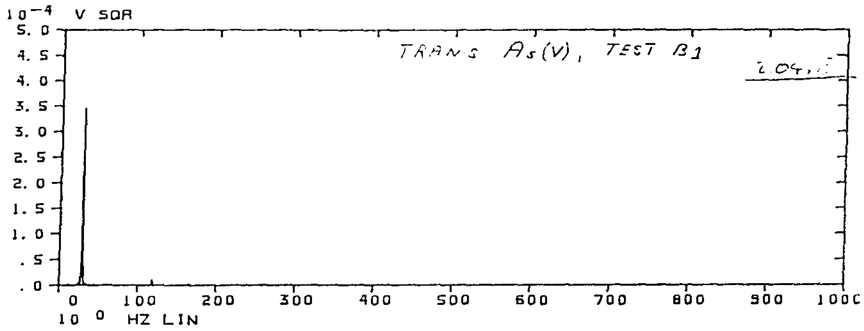
1.18×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operating
4) 30 Hz Off

Test B, Acc. A_4(V) On Monolith Foundation Floor

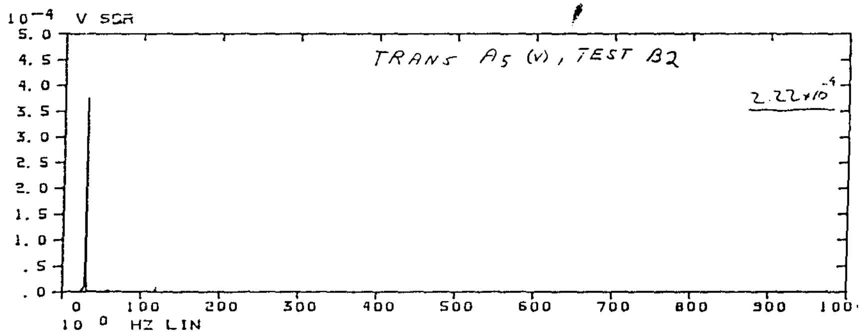
CONDITIONS

G_{RMS}



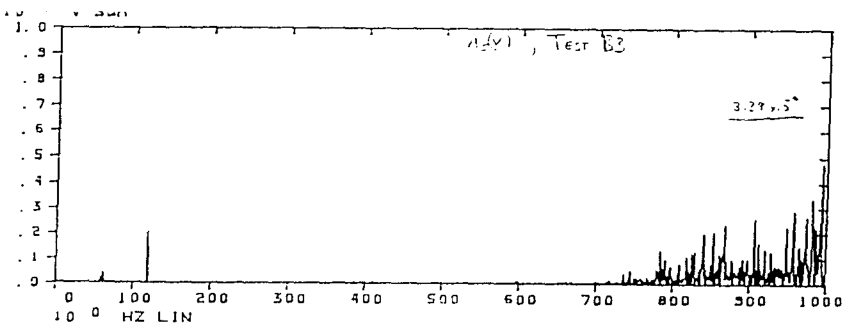
2.04×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On



2.22×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered over A_6, A_7 (Instrumented "I" Beam)
4) 30 Hz On



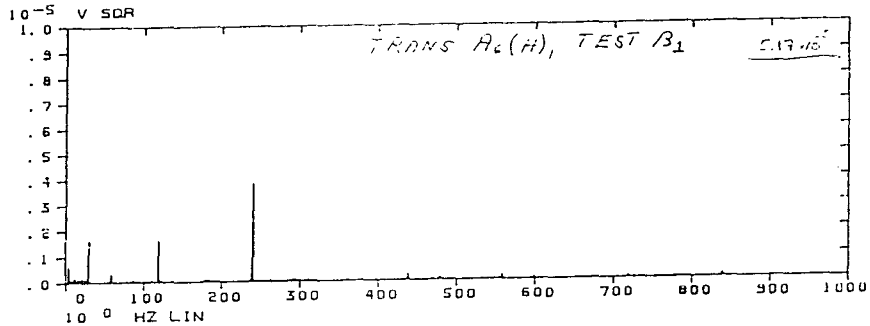
3.39×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operating
4) 30 Hz Off

Test B, Acc. A_5(V) On High-Bay Floor, Near A_4(V)

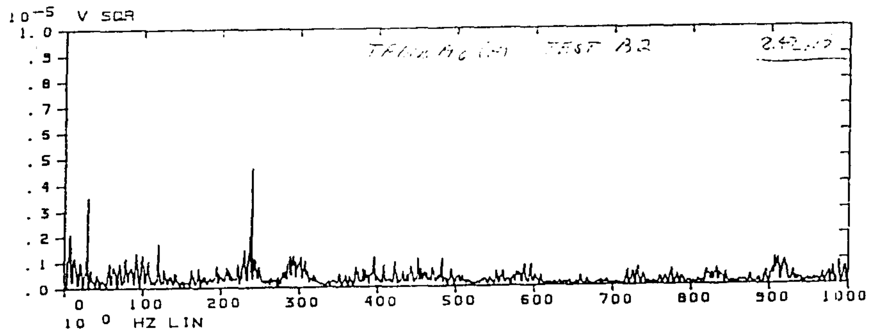
CONDITIONS

G_{RMS}



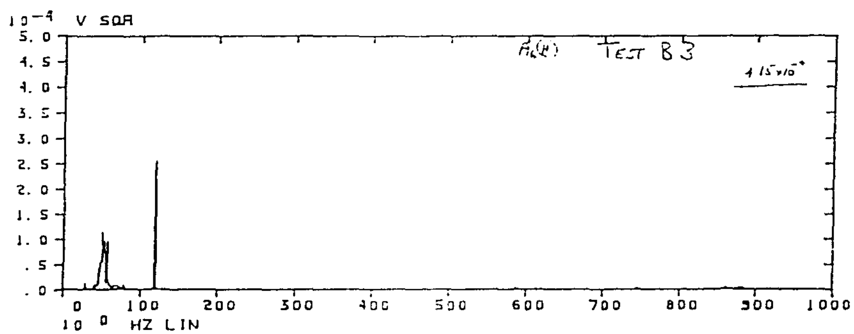
5.17×10^{-5}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On



8.42×10^{-3}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered over A_6,A_7 (Instrumented "I" Beam)
4) 30 Hz On



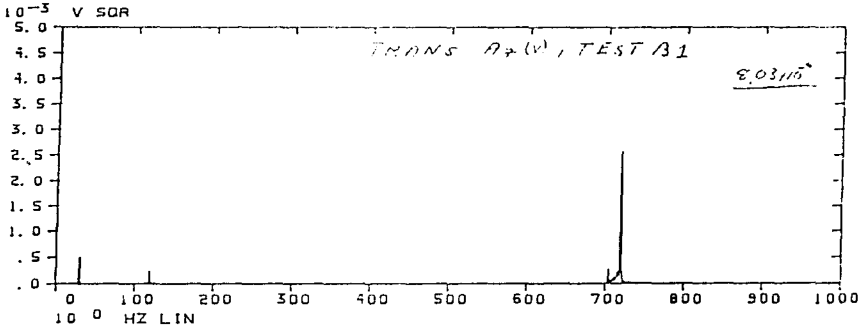
4.15×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operating
4) 30 Hz Off

Test B, Acc. A_6(H), On "I" Beam Supporting Crane Rail

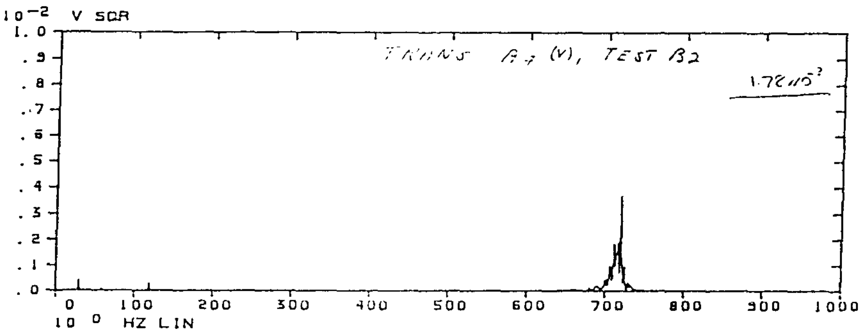
CONDITIONS

G_{RMS}



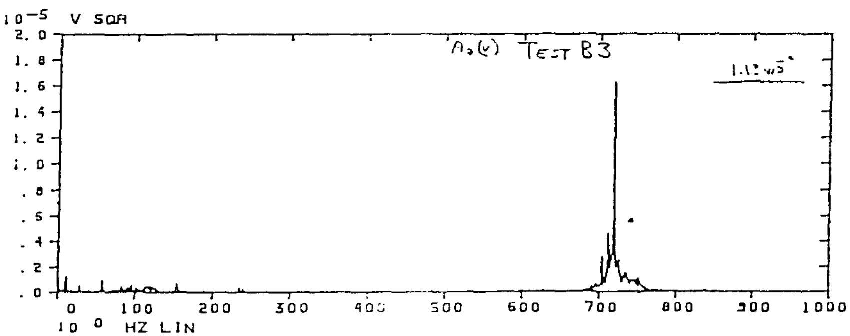
8.03×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On



1.78×10^{-3}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered over A_6,A_7 (Instrumented "I" Beam)
4) 30 Hz On



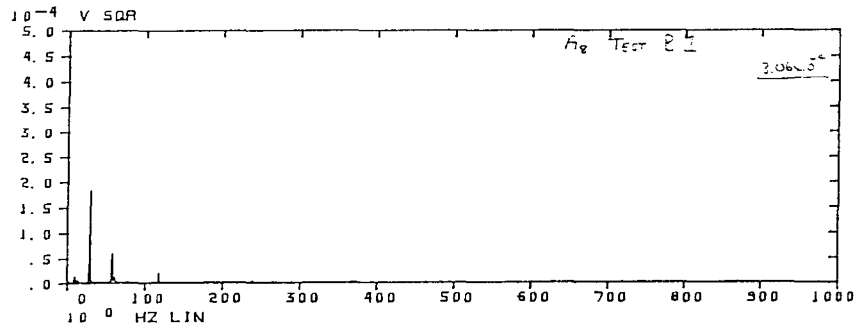
1.13×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operating
4) 30 Hz Off

Test B, Acc. A_7(V) On High Bay Floor (Base of "I" Beam, Near A_6(H))

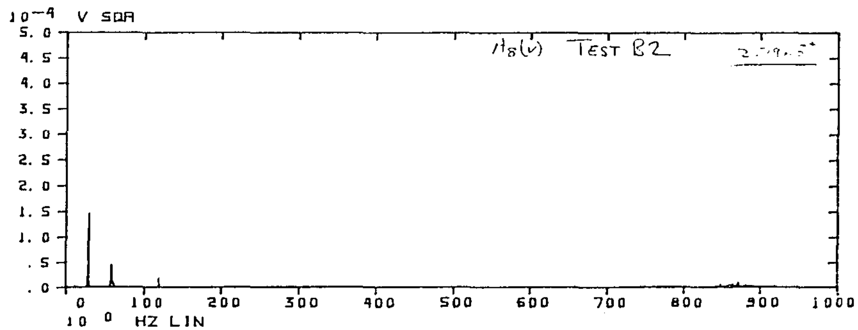
CONDITIONS

G_{RMS}



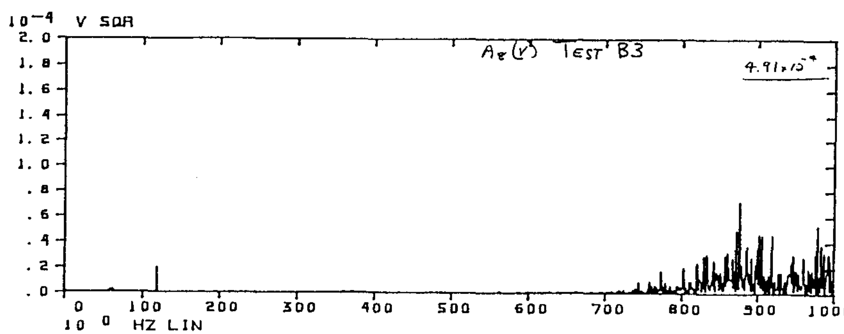
3.06×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On



2.79×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered over A_6,A_7 (Instrumented "I" Beam)
4) 30 Hz On



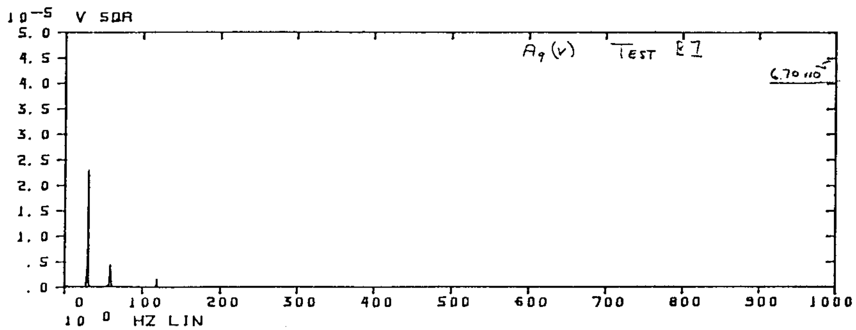
4.91×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operating
4) 30 Hz Off

Test B, Acc. A_8(V) On High-Bay Floor, Near East Crane "I" Beam

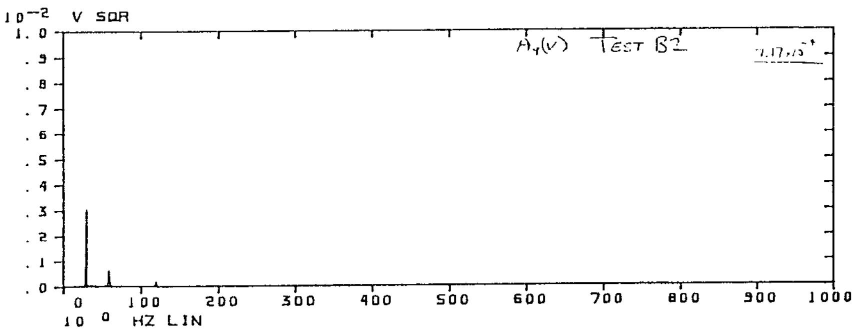
CONDITIONS

G_{RMS}



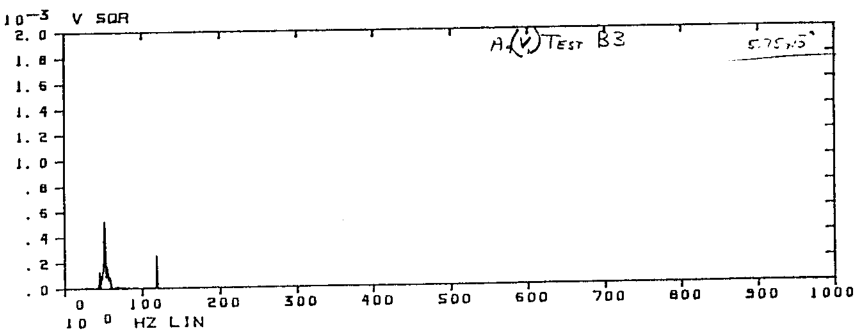
6.70×10^{-5}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On



7.17×10^{-4}

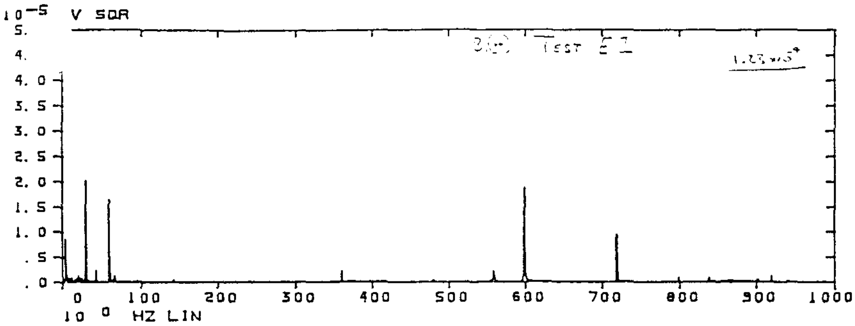
1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered over A_6, A_7 (Instrumented "I" Beam)
4) 30 Hz On

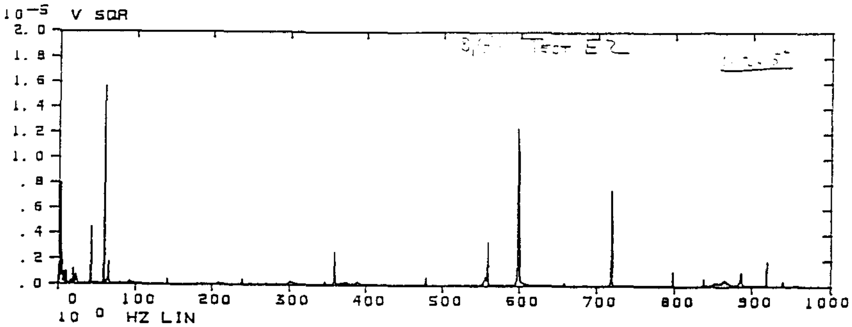


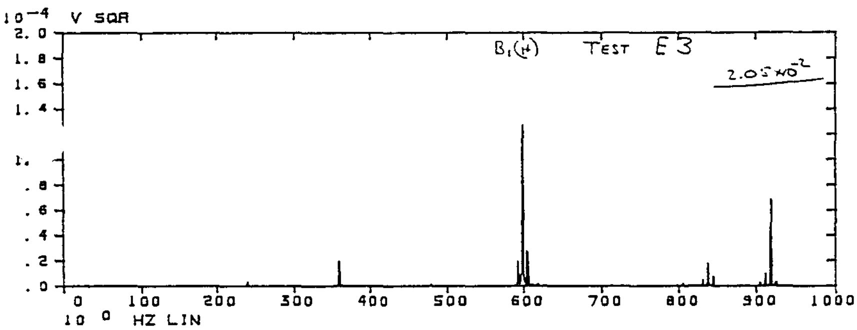
5.75×10^{-4}

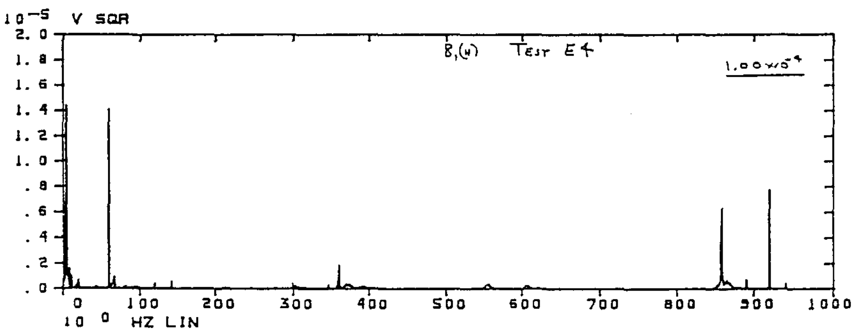
1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operating
4) 30 Hz Off

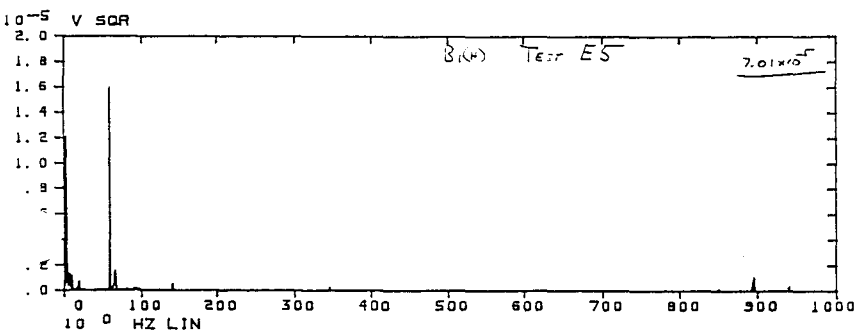
Test B, Acc. A_9(V) On High-Bay Floor, West of A_6







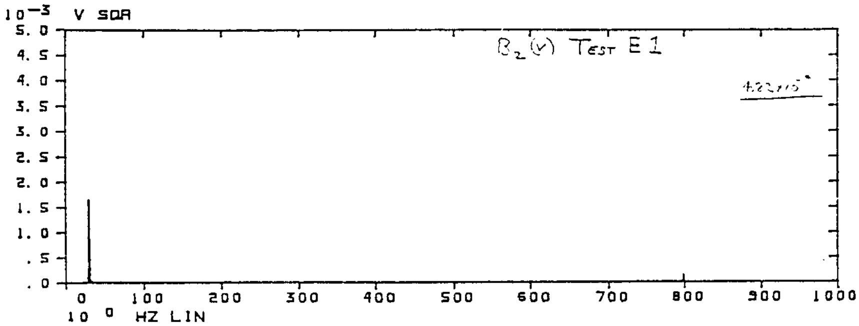


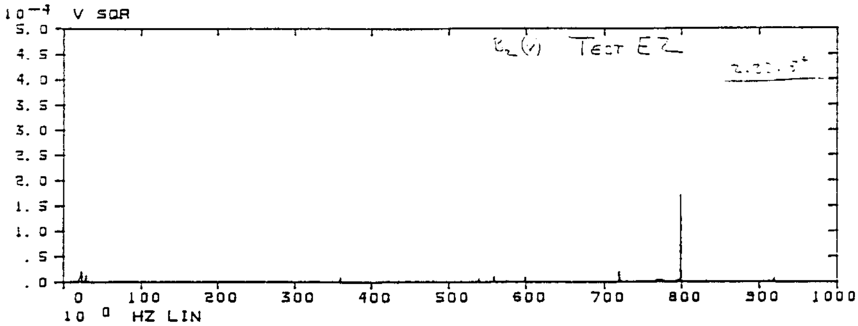


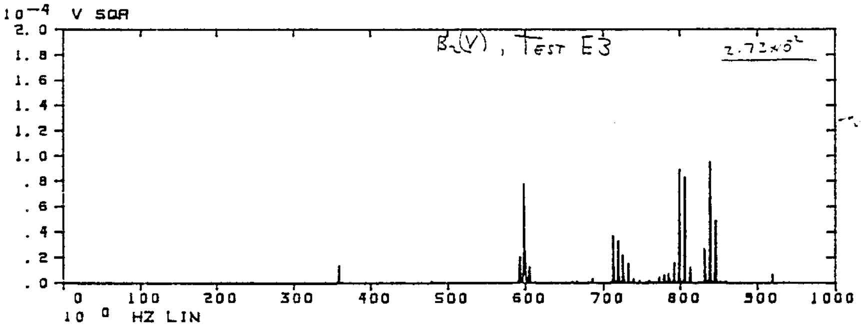
		CONDITIONS		
G_{RMS}	30 Hz	H_2O	BM	QM
1.23×10^{-4}	On	On	Off	Off
1.12×10^{-4}	Off	On	Off	Off
2.05×10^{-2}	Off	On	On 1500A	Off
1.00×10^{-4}	Off	On	Off	On 250A
7.01×10^{-5}	Off	Off	Off	Off

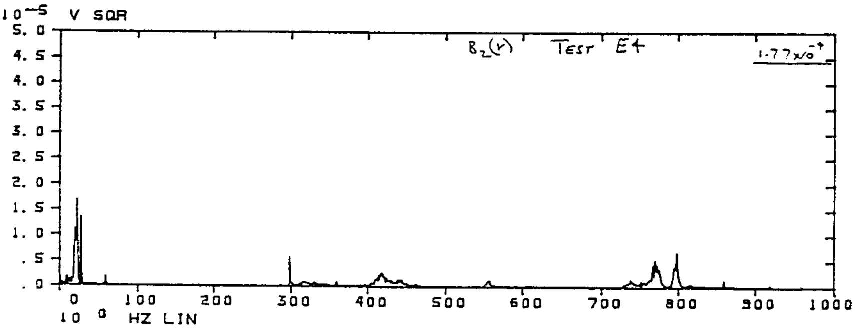
Test E, Acc. B_1(H), On Bending Magnet

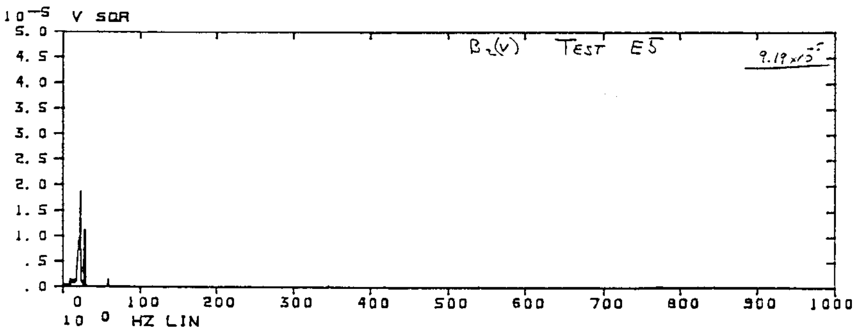
CONDITIONS







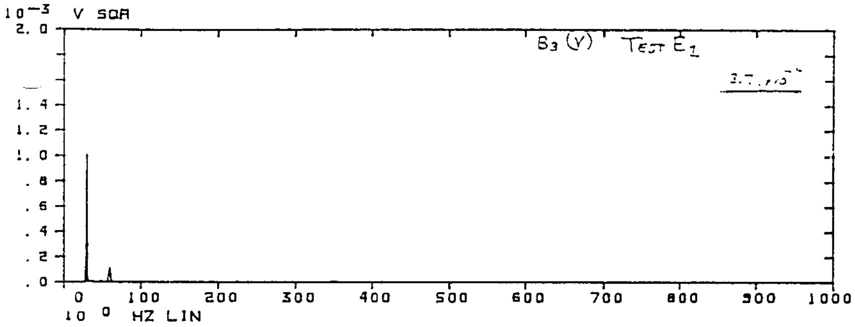


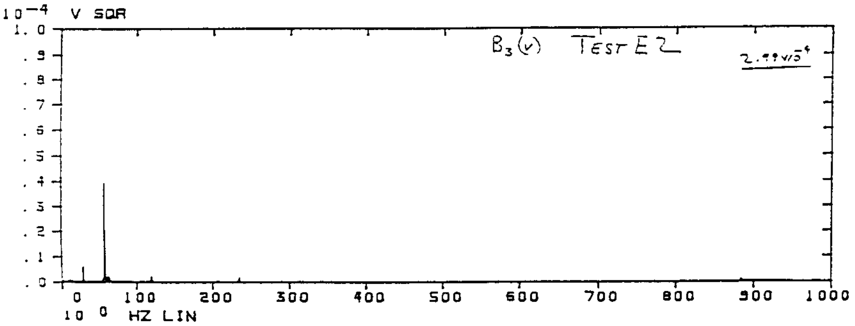


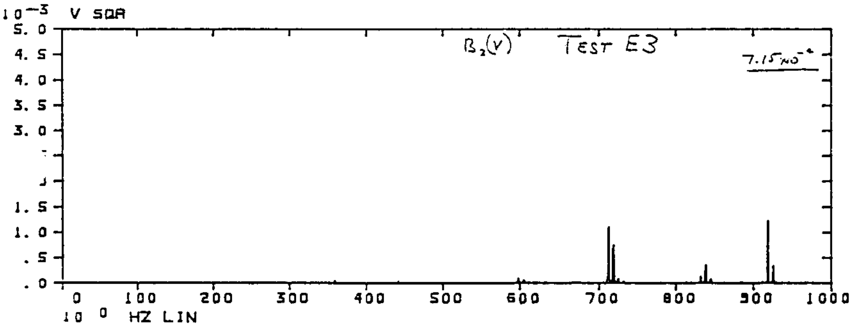
Test	G_{RMS}	30 Hz	H_2O	BM	QM
E1	4.82×10^{-4}	On	On	Off	Off
E2	2.33×10^{-4}	Off	On	Off	Off
E3	2.73×10^{-2}	Off	On	On 1500A	Off
E4	1.77×10^{-4}	Off	On	Off	On 250A
E5	9.19×10^{-5}	Off	Off	Off	Off

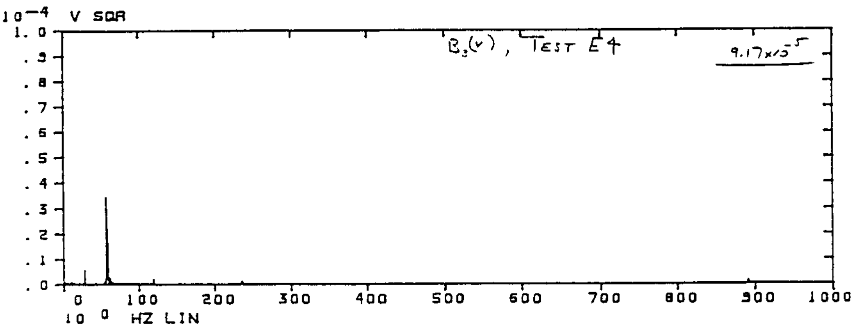
Test E, Acc. B_2(V) On Bending Magnet

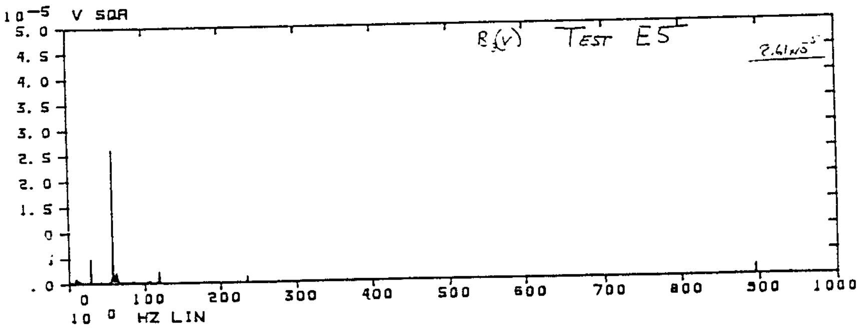
CONDITIONS





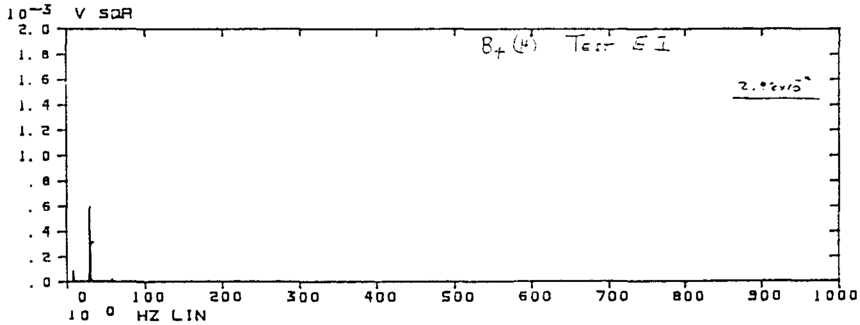


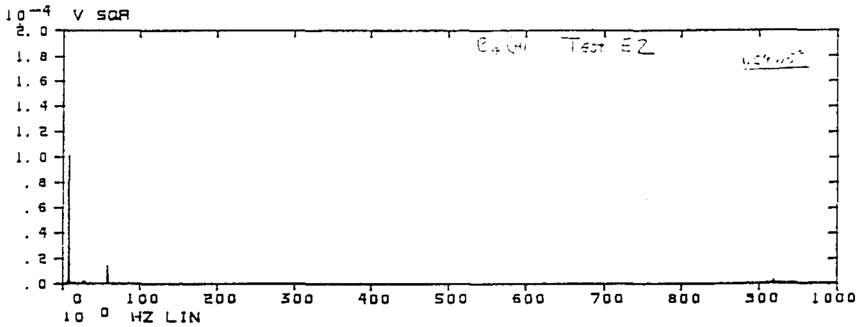


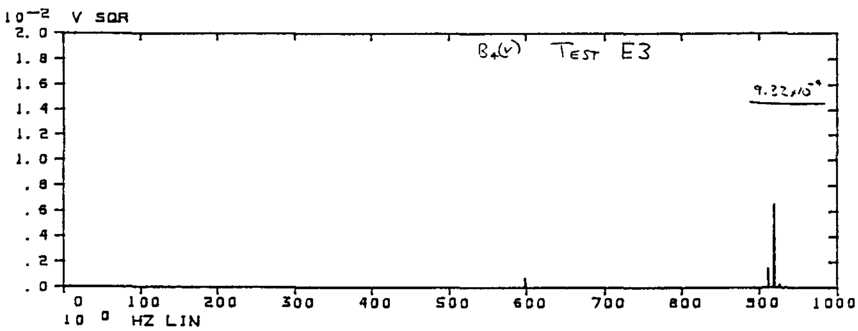


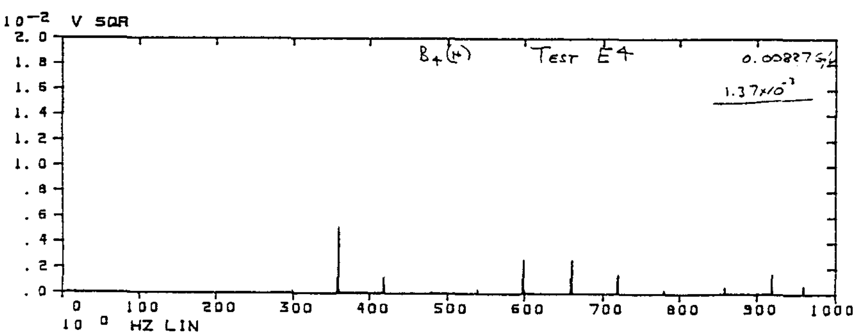
G_{RMS}	30 Hz	H_2O	BM	QM
3.71×10^{-4}	On	On	Off	Off
2.99×10^{-4}	Off	On	Off	Off
7.15×10^{-4}	Off	On	On 1500A	Off
9.17×10^{-5}	Off	On	Off	On 250A
8.61×10^{-5}	Off	Off	Off	Off

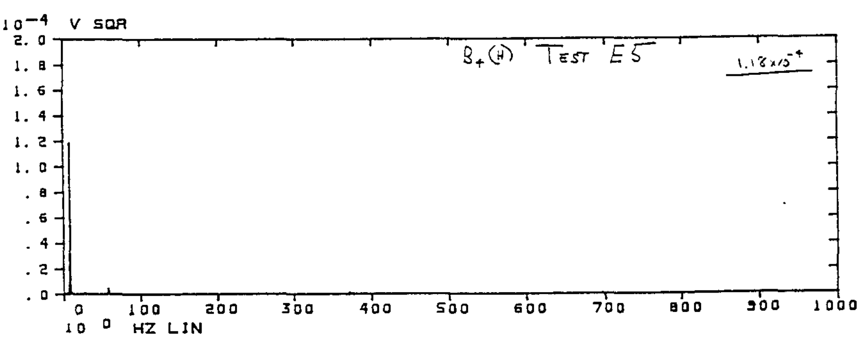
Test E, Acc. B_3(V) On Floor at Base of Bending Magnet







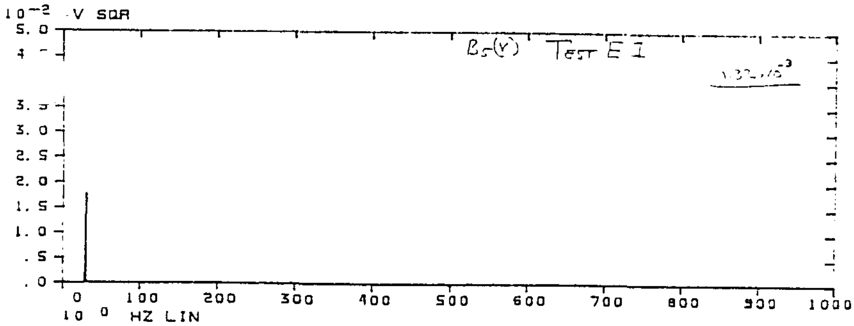


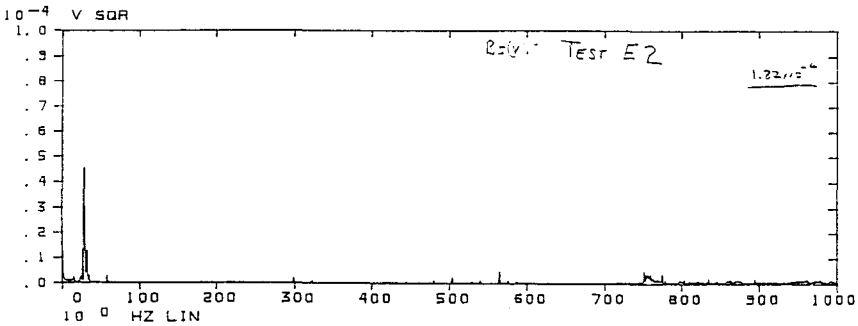


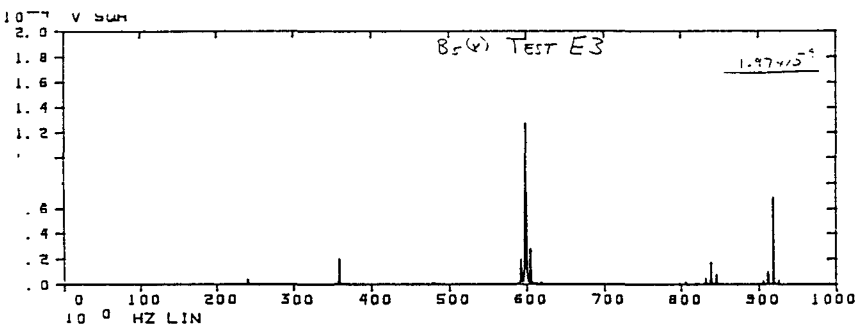
CONDITIONS

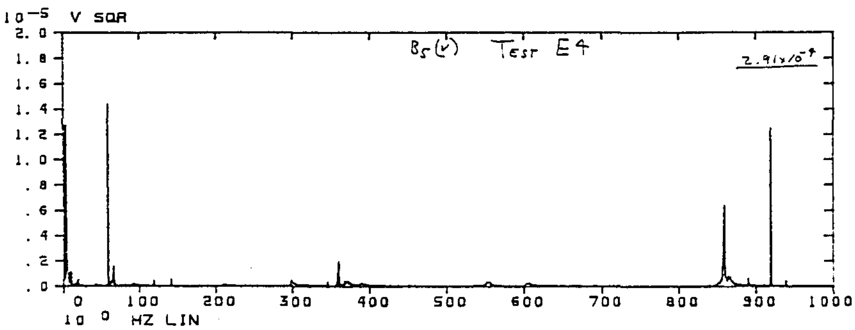
G_{RMS}	30 Hz	H_2O	BM	QM
2.98×10^{-4}	On	On	Off	Off
1.59×10^{-4}	Off	On	Off	Off
9.32×10^{-4}	Off	On	On 1500A	Off
1.37×10^{-3}	Off	On	Off	On 250A
1.18×10^{-4}	Off	Off	Off	Off

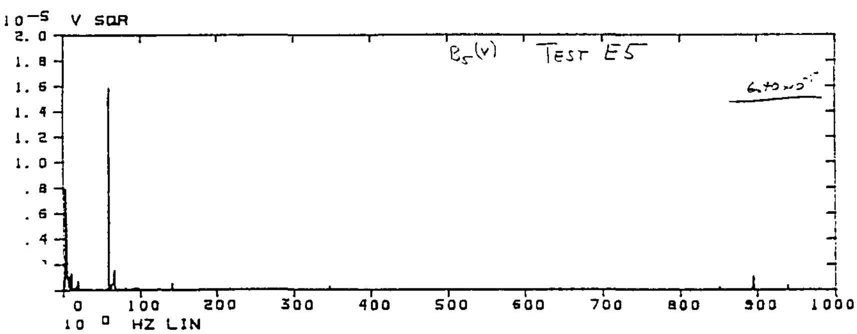
Test E, Acc. B_4(H) On QM 2001





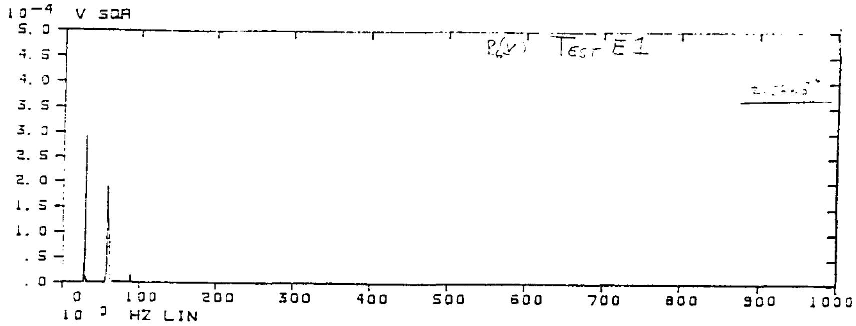


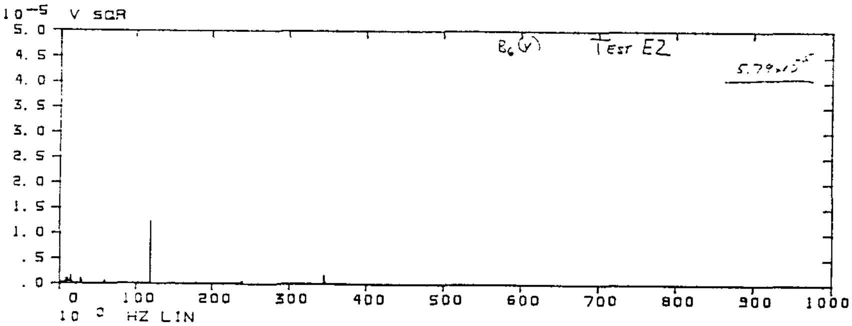


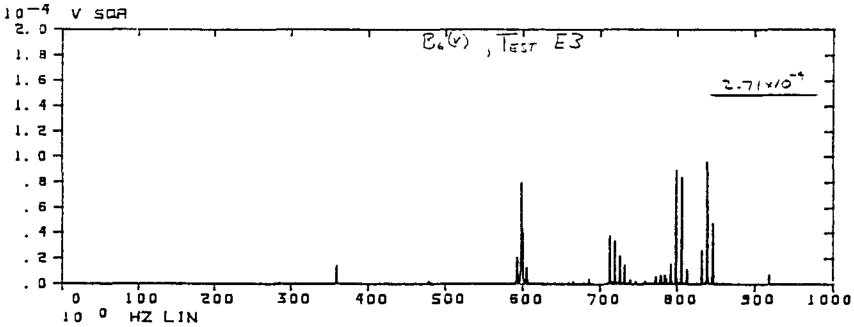


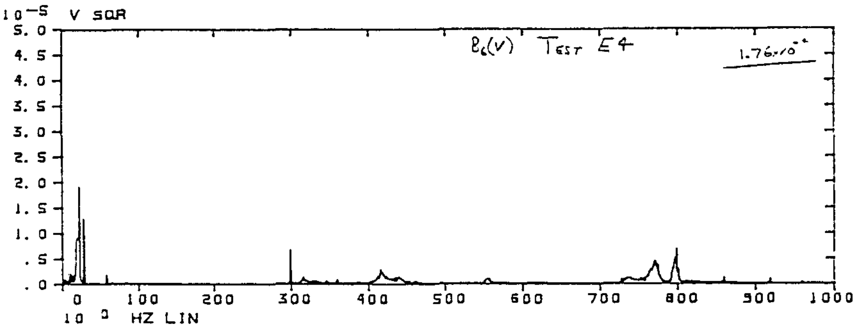
		CONDITIONS			
	G_{RMS}	30 Hz	H_2O	BM	QM
Test E1	1.32×10^{-3}	On	On	Off	Off
Test E2	1.87×10^{-4}	Off	On	Off	Off
Test E3	1.97×10^{-4}	Off	On	On 1500A	Off
Test E4	2.91×10^{-4}	Off	On	Off	On 250A
Test E5	6.40×10^{-5}	Off	Off	Off	Off

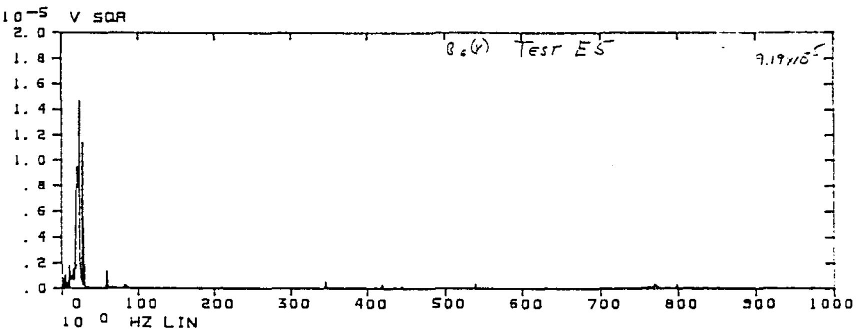
Test E, Acc. B_5(V) On QM 2001





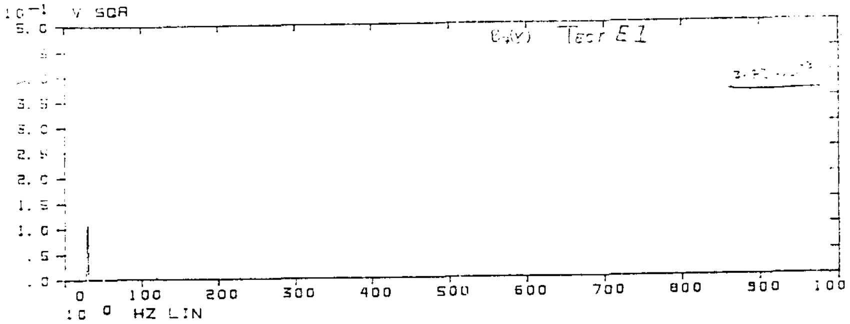


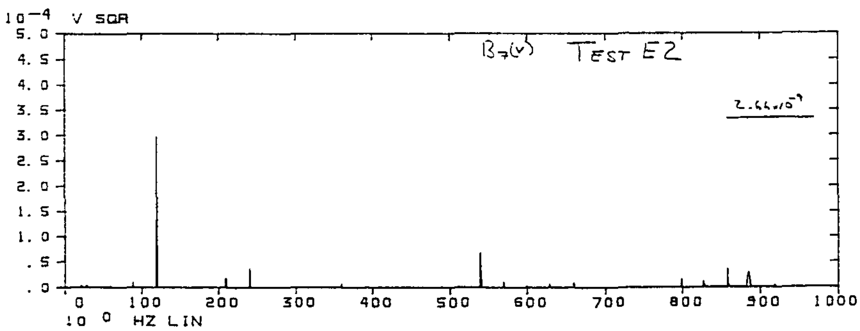


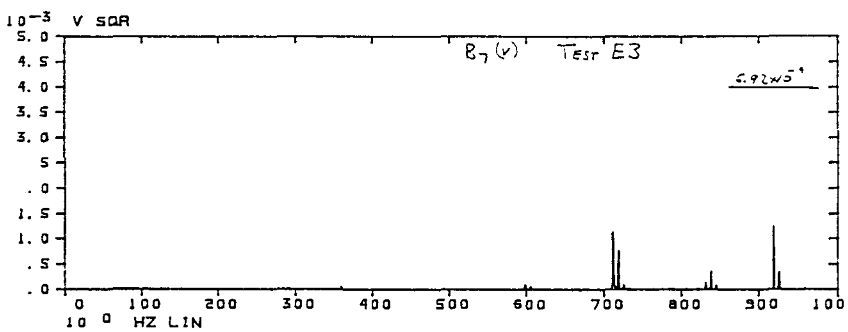


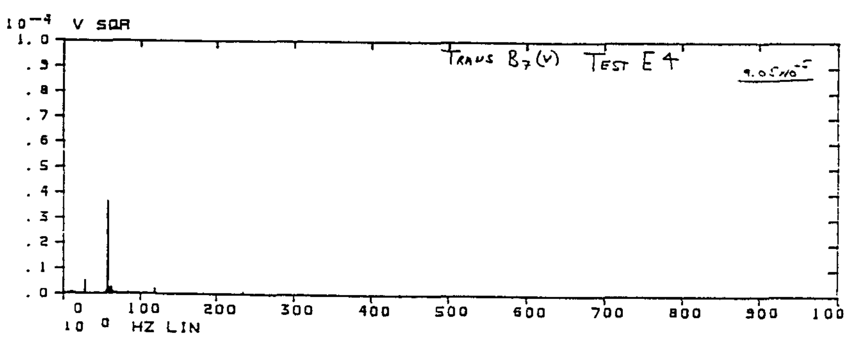
	CONDITIONS			
G_{RMS}	30 Hz	H_2O	BM	QM
2.56×10^{-4}	On	On	Off	Off
5.79×10^{-5}	Off	On	Off	Off
2.71×10^{-4}	Off	On	On 1500A	Off
1.76×10^{-4}	Off	On	Off	On 250A
9.19×10^{-5}	Off	Off	Off	Off

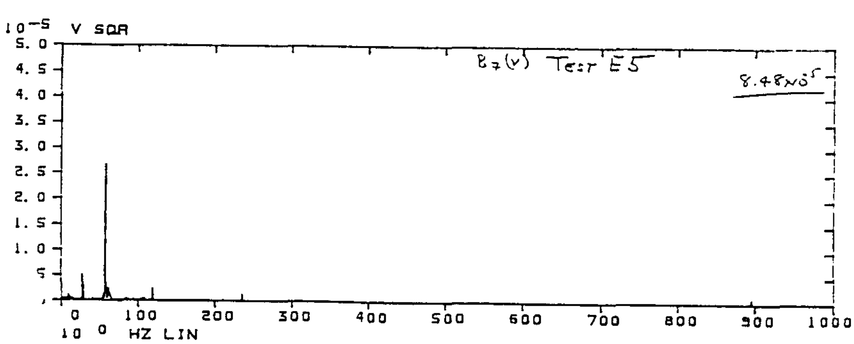
Test E, Acc. B_6(V) On Floor at Base of QM 2006











	CONDITIONS			
G_{RMS}	30 Hz	H_2O	BM	QM
3.42×10^{-3}	On	On	Off	Off
2.66×10^{-4}	Off	On	Off	Off
6.92×10^{-4}	Off	On	On 1500A	Off
9.05×10^{-5}	Off	On	Off	On 250A
8.48×10^{-5}	Off	Off	Off	Off

Test E, Acc. B_7(V) On Floor Near Storage Ring Magnets

APPENDIX B

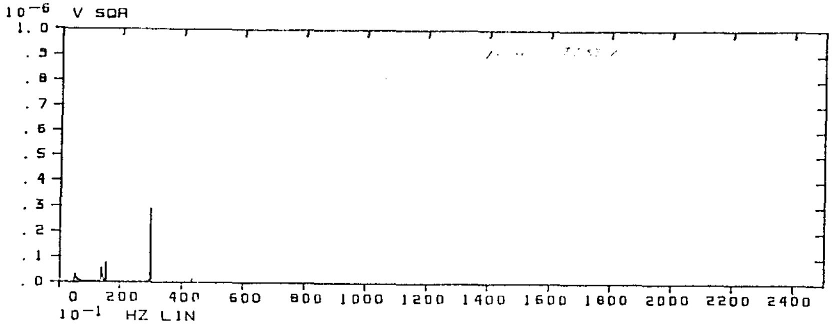
Test Series A, B, and E

Displacement PSDs - Frequency range 5 to 250 Hz

RMS Displacements - Frequency range 5 to 250 Hz (number without underline)
Contribution at 30 Hz (number with solid underline)
Frequency range 10 to 250 Hz with 30 Hz contribution
filtered out (number with dashed underline)

CONDITIONS

in.$_{RMS}$

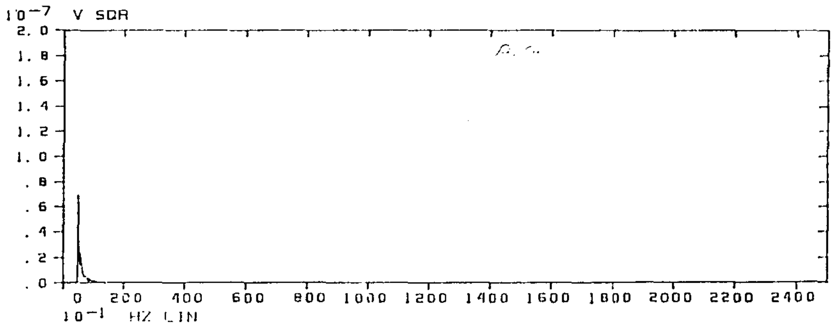


8.19×10^{-6}

5.05×10^{-6}

5.2×10^{-6}

1) IPNS Not Operating
2) Vent. Fans Off

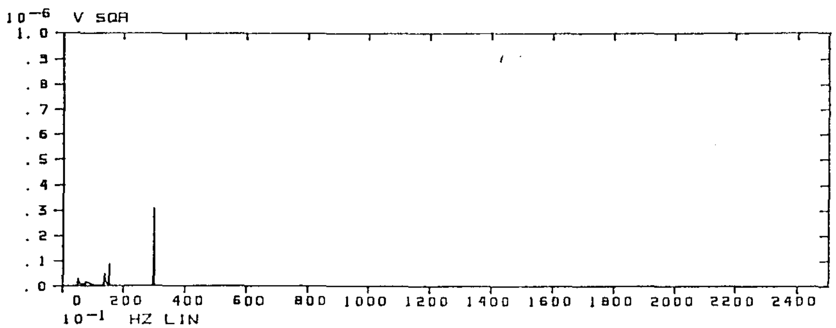


4.49×10^{-4}

2.37×10^{-5}

1.34×10^{-4}

1) IPNS Not Operating
2) Pump Operating (Normal Operational Flow)
3) Vent. Fans Off



8.85×10^{-6}

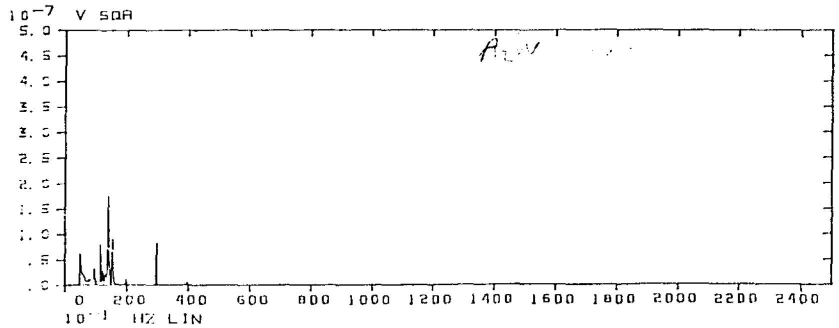
5.17×10^{-6}

5.26×10^{-6}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Disp. [A_1(H)] On Pump

CONDITIONS



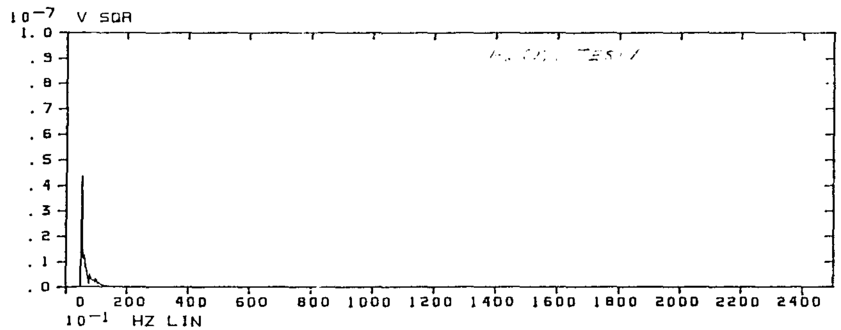
in.$_{RMS}$

1.03×10^{-5}

2.70×10^{-6}

8.21×10^{-6}

1) IPNS Not Operating
2) Vent. Fans Off

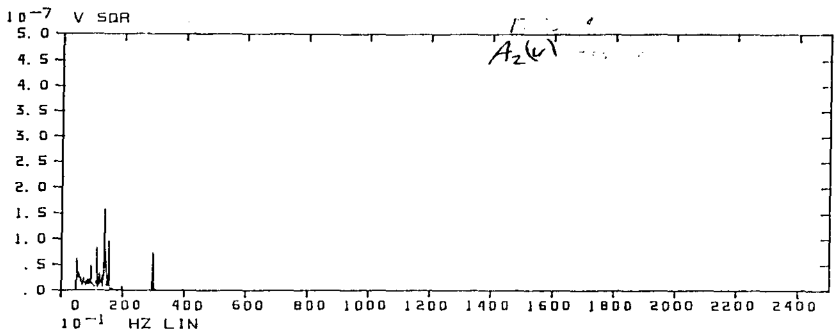


4.27×10^{-4}

1.98×10^{-5}

1.59×10^{-4}

1) IPNS Not Operating
2) Pump Operating (Normal Operational Flow)
3) Vent. Fans Off



1.08×10^{-5}

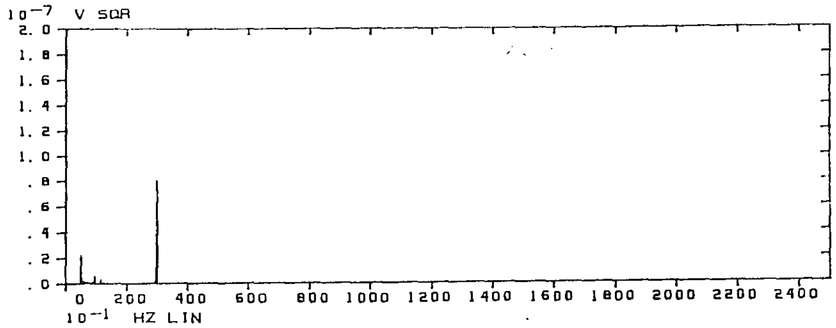
2.62×10^{-6}

8.36×10^{-6}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Disp. [A_2(V)] On Pump

CONDITIONS



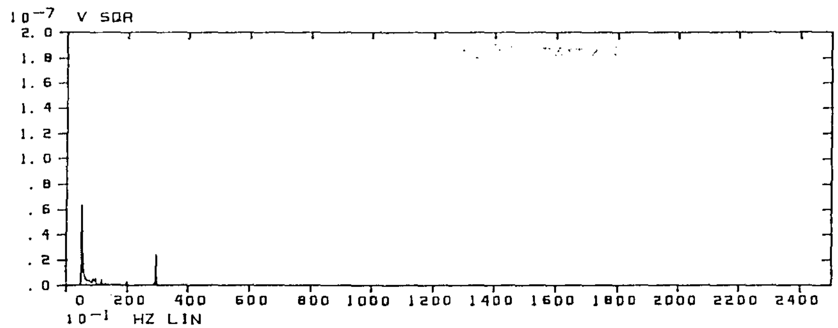
in.$_{RMS}$

3.58×10^{-6}

2.67×10^{-6}

1.02×10^{-6}

1) IPNS Not Operating
2) Vent. Fans Off

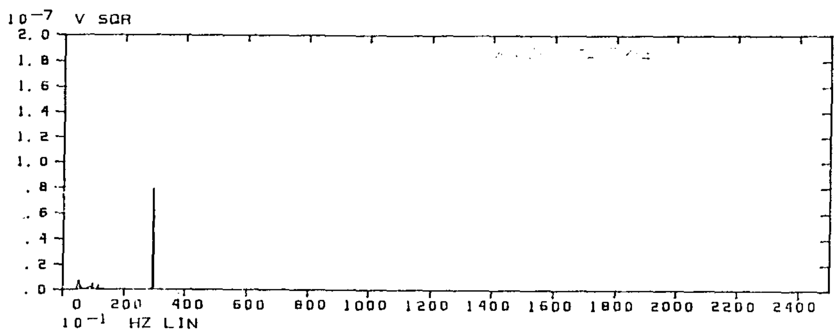


4.63×10^{-6}

1.65×10^{-6}

1.82×10^{-6}

1) IPNS Not Operating
2) Pump Operating (Normal Operational Flow)
3) Vent. Fans Off



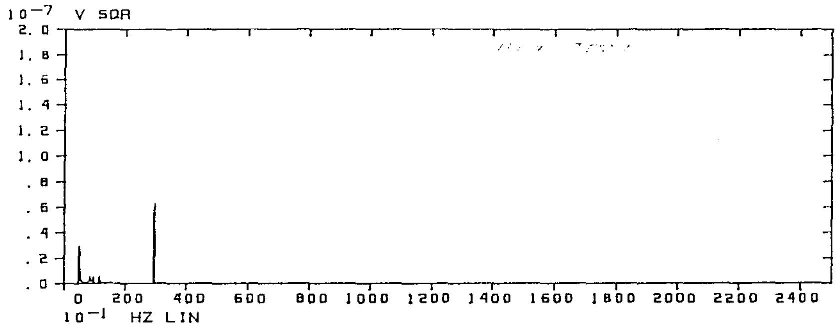
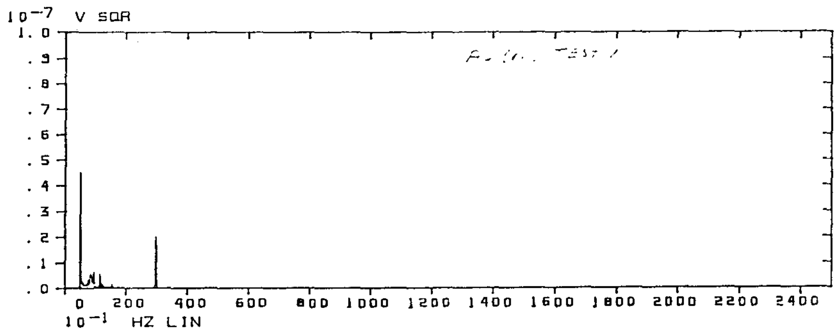
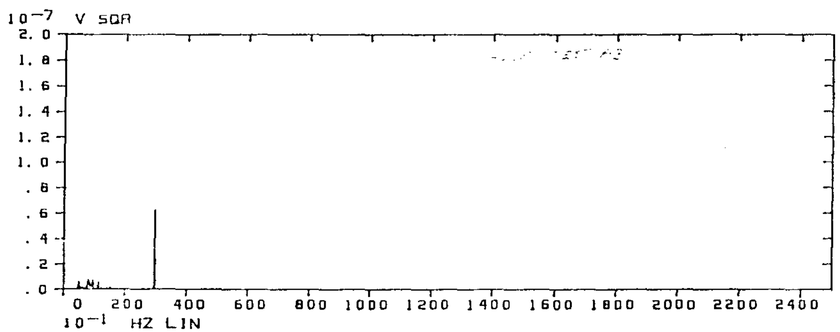
3.42×10^{-6}

2.61×10^{-6}

1.01×10^{-6}

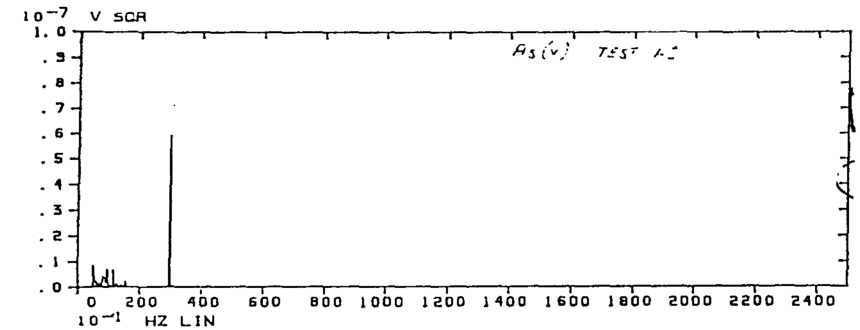
1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Disp. [A_3(H)] On South Wall of Monolith

	in.$_{RMS}$	CONDITIONS
	3.53×10^{-6} 2.28×10^{-6} 1.28×10^{-6}	1) IPNS Not Operating 2) Vent. Fans Off
	3.35×10^{-6} 1.35×10^{-6} 1.40×10^{-6}	1) IPNS Not Operating 2) Pump Operating (Normal Operational Flow) 3) Vent. Fans Off
	3.36×10^{-6} 2.27×10^{-6} 1.27×10^{-6}	1) IPNS Not Operating 2) Pump Off 3) Vent. Fans On

Test A, Disp. $[A_4(V)]$ On Monolith Foundation Floor

CONDITIONS



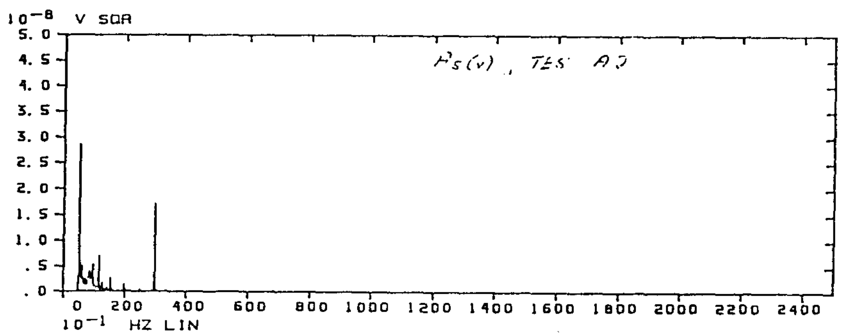
in.$_{RMS}$

3.33×10^{-6}

2.18×10^{-6}

1.37×10^{-6}

1) IPNS Not Operating
2) Vent. Fans Off

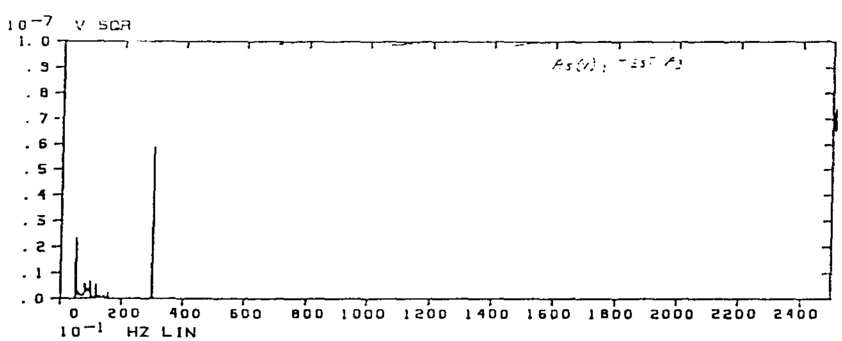


3.24×10^{-6}

1.21×10^{-6}

1.6×10^{-6}

1) IPNS Not Operating
2) Pump Operating (Normal Operational Flow)
3) Vent. Fans Off



3.55×10^{-6}

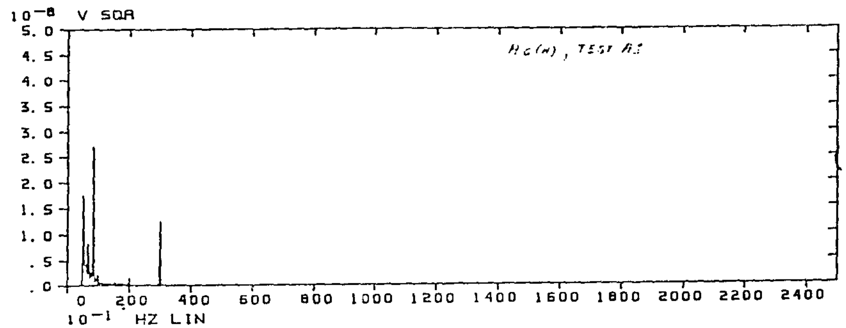
2.15×10^{-6}

1.39×10^{-6}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Disp. [A_5(V)] On High-Bay Floor Near A_4(V)

CONDITIONS



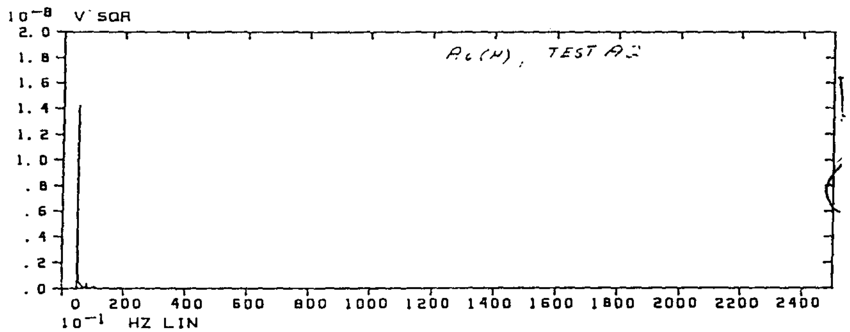
in. RMS

3.27×10^{-6}

1.02×10^{-6}

1.26×10^{-6}

1) IPNS Not Operating
2) Vent. Fans Off

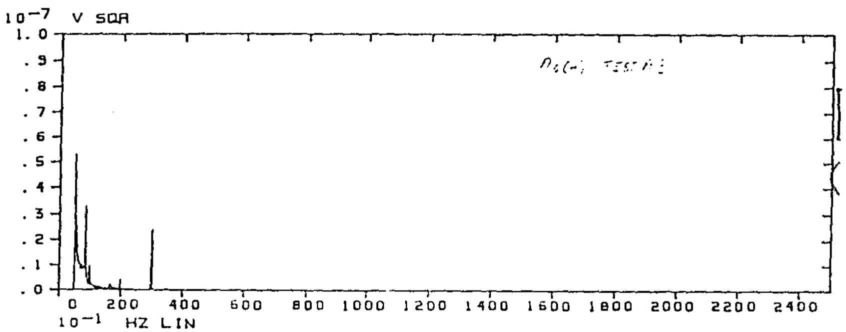


1.25×10^{-4}

2.70×10^{-6}

2.48×10^{-5}

1) IPNS Not Operating
2) Pump Operating (Normal Operational Flow)
3) Vent. Fans Off



5.36×10^{-6}

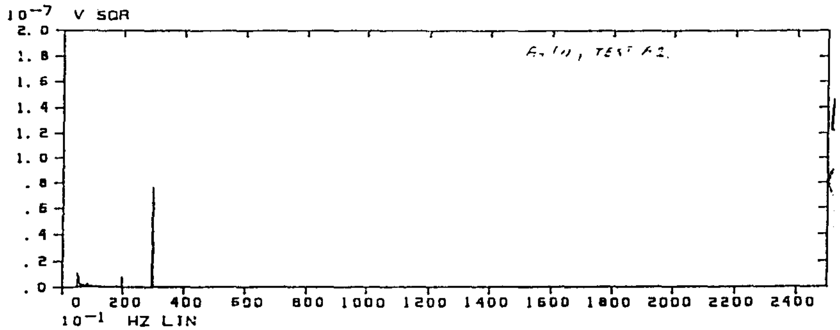
1.44×10^{-6}

2.06×10^{-6}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Disp. [A_6(H)] On "I" Beam Supporting Crane Rail (Near A_7)

CONDITIONS



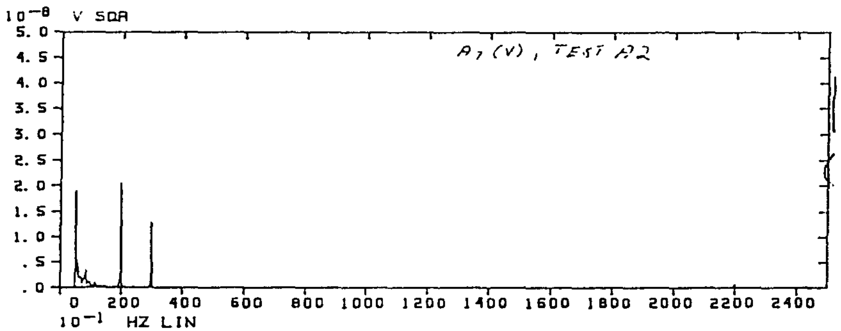
in. RMS

3.53×10^{-6}

2.52×10^{-6}

1.24×10^{-6}

1) IPNS Not Operating
2) Vent. Fans Off

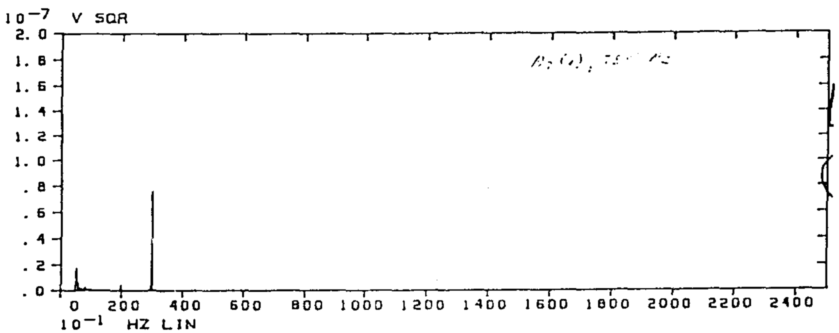


3.11×10^{-6}

1.07×10^{-6}

1.91×10^{-6}

1) IPNS Not Operating
2) Pump Operating (Normal Operational Flow)
3) Vent. Fans Off



3.54×10^{-6}

2.49×10^{-6}

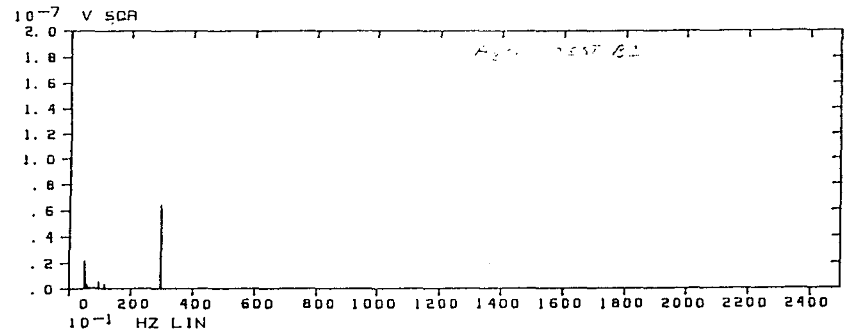
1.20×10^{-6}

1) IPNS Not Operating
2) Pump Off
3) Vent. Fans On

Test A, Disp. [A_7(V)] On High-Bay Floor at Base of Crane "I" Beam

CONDITIONS

in.$_{RMS}$

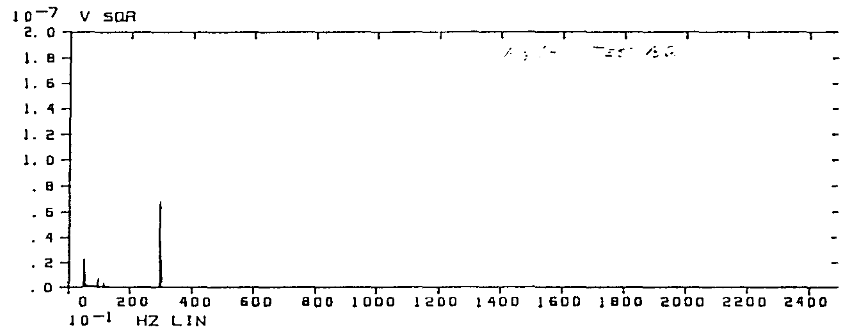


3.43×10^{-6}

2.36×10^{-6}

9.98×10^{-7}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On

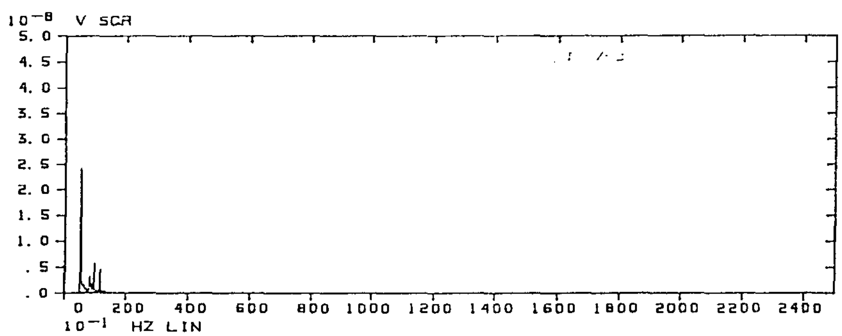


3.47×10^{-6}

2.44×10^{-6}

1.16×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered Over A_6-A_7 (Instrumented "I" Beam)
4) 30 Hz On



2.41×10^{-6}

9.07×10^{-8}

9.92×10^{-7}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operational
4) 30 Hz Off

Test B, Disp. [A_3(H)]   South Wall of Monolith

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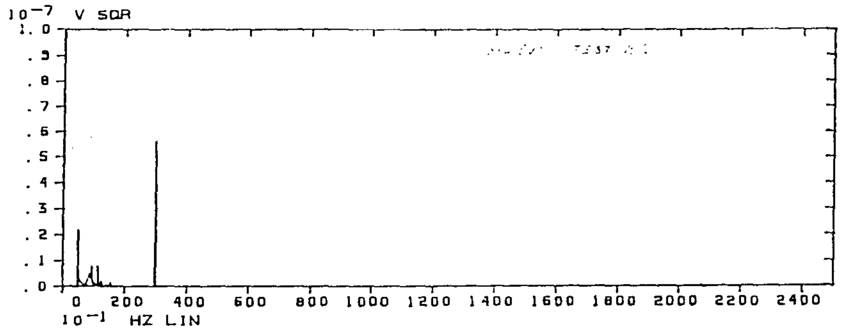
CONDITIONS

in.$_{RMS}$

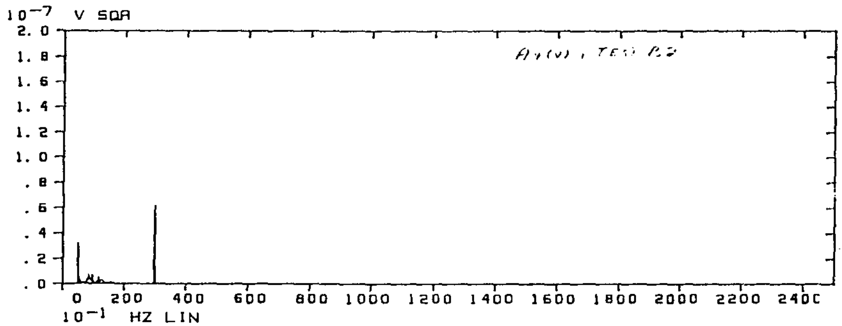


3.50×10^{-6}

2.14×10^{-6}

1.45×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On

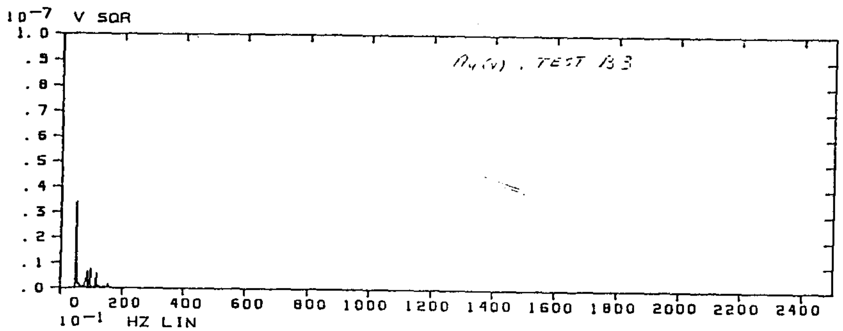


3.88×10^{-6}

2.26×10^{-6}

1.74×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered Over A_6-A_7 (Instrumented "I" Beam)
4) 30 Hz On



2.81×10^{-6}

1.61×10^{-7}

1.27×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operational
4) 30 Hz Off

B10

Test B, Disp. [A_4(V)] On Monolith Foundation Floor

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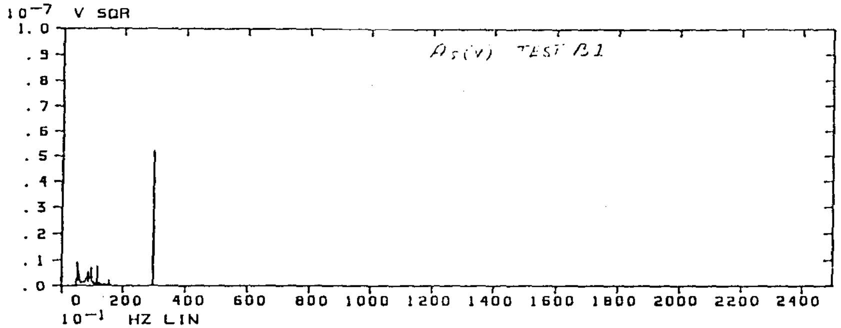
CONDITIONS

in. RMS

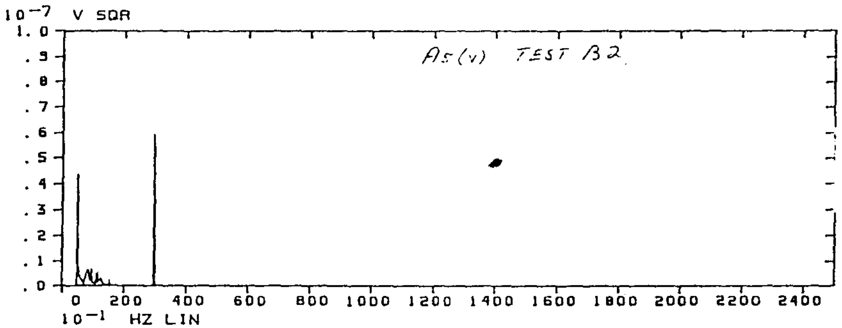


3.39×10^{-6}

2.02×10^{-6}

1.54×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On

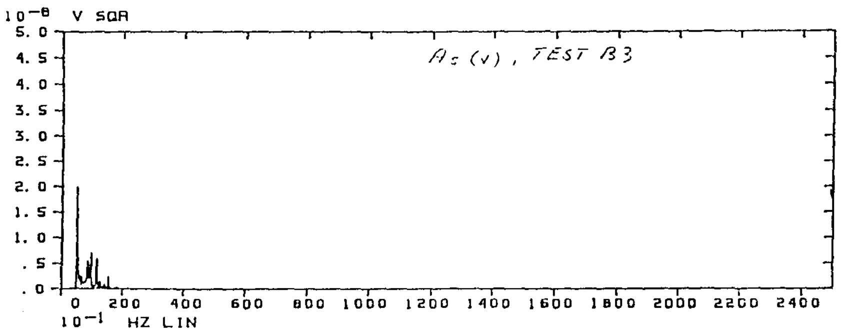


4.08×10^{-6}

2.16×10^{-6}

1.82×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered Over A_6-A_7 (Instrumented "I" Beam)
4) 30 Hz On



2.75×10^{-6}

1.98×10^{-7}

1.35×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operational
4) 30 Hz Off

Test B, Disp. [A_5(V)] On High-Bay Floor Near A_4

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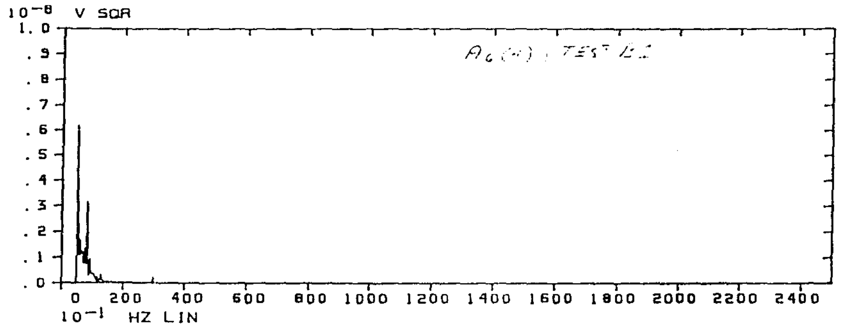
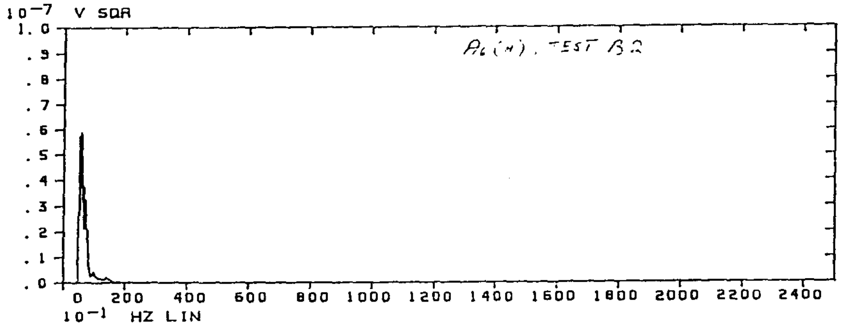
CONDITIONS



in.$_{RMS}$

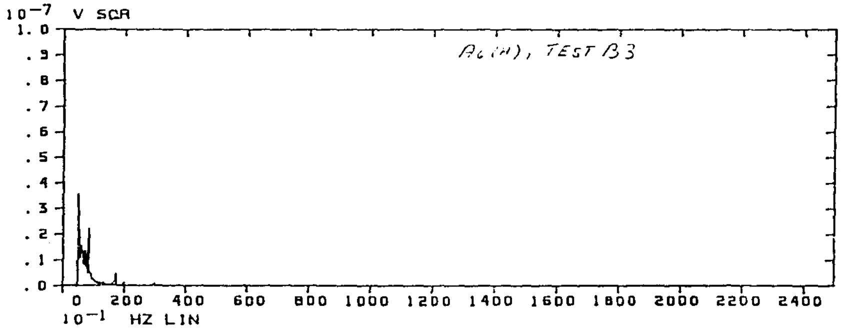
1.68×10^{-5}
1.46×10^{-6}
6.16×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On



6.71×10^{-5}
2.37×10^{-6}
2.08×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered Over A_6-A_7 (Instrumented "I" Beam)
4) 30 Hz On



4.93×10^{-6}
4.94×10^{-7}
2.04×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operational
4) 30 Hz Off

9-4

Test B, Disp. [A_6(H)] On "I" Beam Supporting Crane Rail

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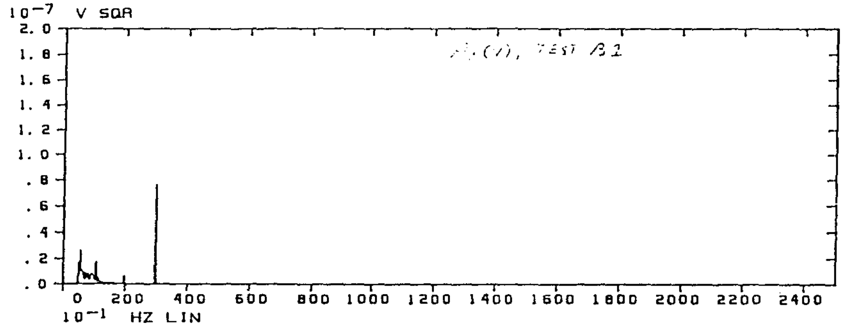
CONDITIONS

in. RMS

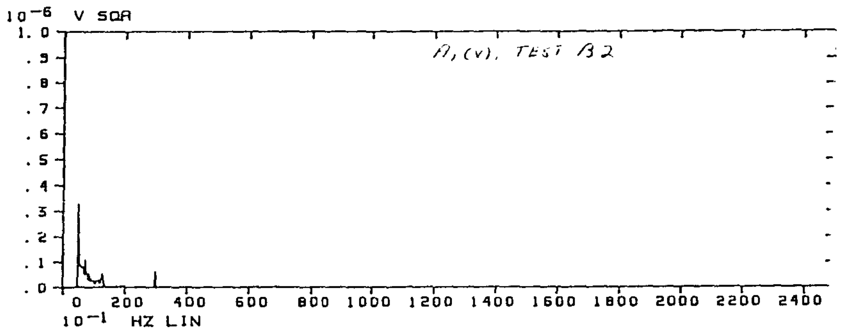


5.20×10^{-6}

2.49×10^{-6}

2.66×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On

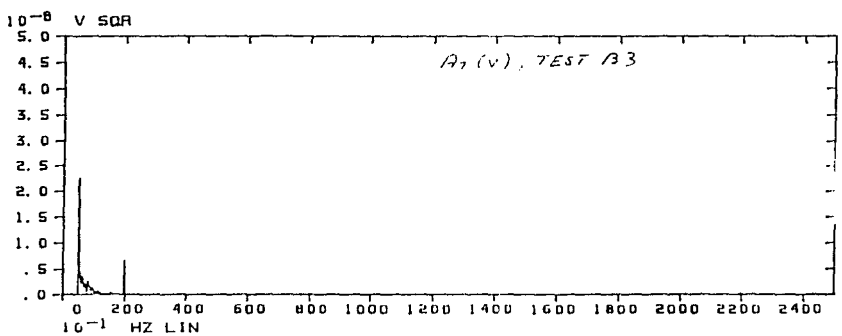


1.31×10^{-5}

2.32×10^{-6}

6.70×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered Over A_6-A_7 (Instrumented "I" Beam)
4) 30 Hz On



2.57×10^{-6}

1.53×10^{-7}

1.26×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operational
4) 30 Hz Off

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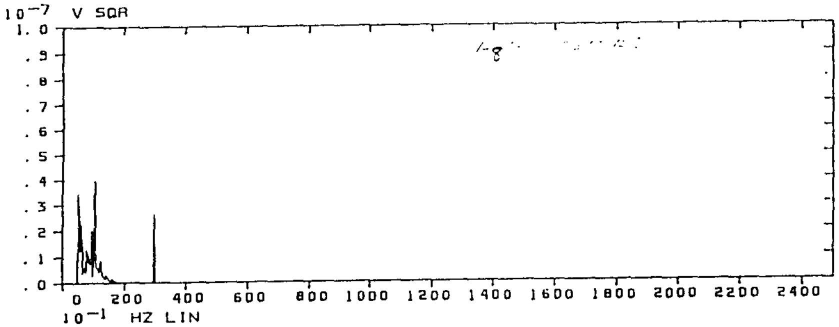
Test B, Disp. [A_7(V)] On High y Floor (Base of "I" Beam, Near A_6(H))

CONDITIONS



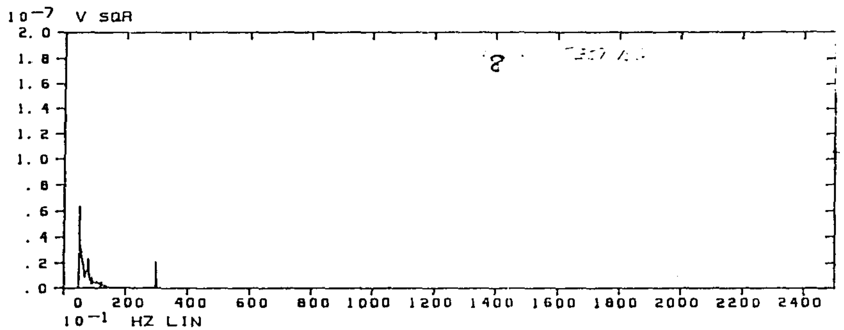
in.$_{RMS}$

3.43×10^{-6}

2.32×10^{-6}

1.93×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On

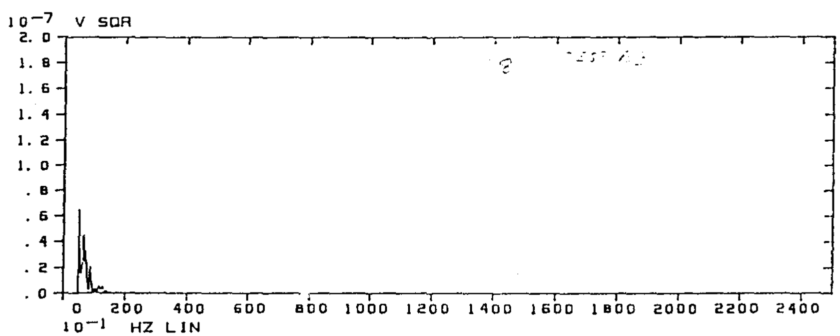


6.23×10^{-6}

1.35×10^{-6}

2.56×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered Over A_6-A_7 (Instrumented "I" Beam)
4) 30 Hz On



6.37×10^{-6}

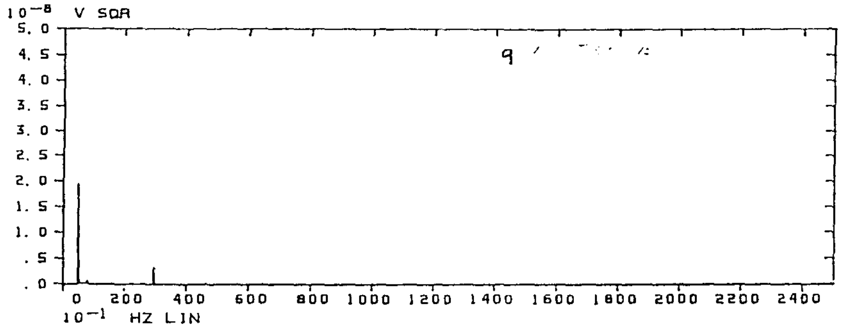
1.69×10^{-7}

2.46×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operational
4) 30 Hz Off

Test B, Disp. [A_8(V)] On High-Bay Floor, Near East Crane "I" Beam

CONDITIONS



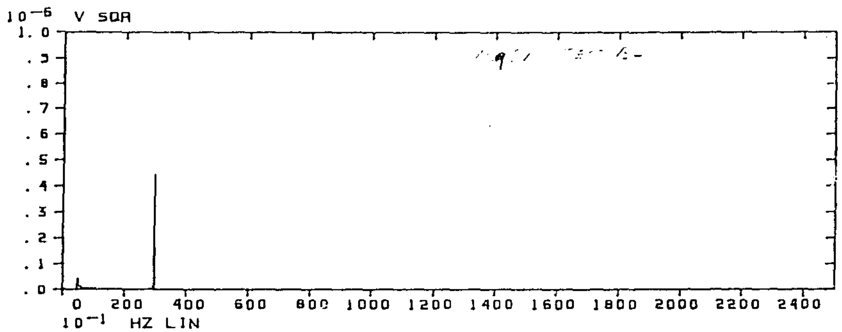
in. RMS

1.59×10^{-6}

5.43×10^{-7}

3.13×10^{-7}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On

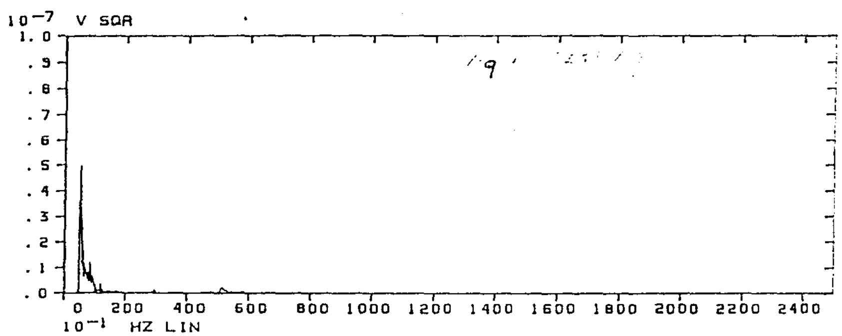


7.51×10^{-6}

6.17×10^{-6}

2.41×10^{-6}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered Over A_6-A_7 (Instrumented "I" Beam)
4) 30 Hz On



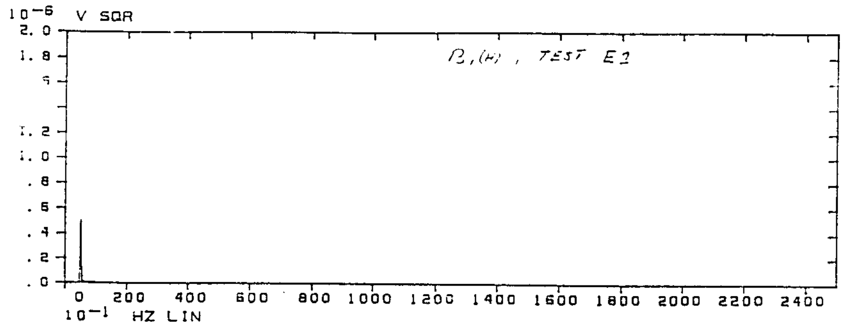
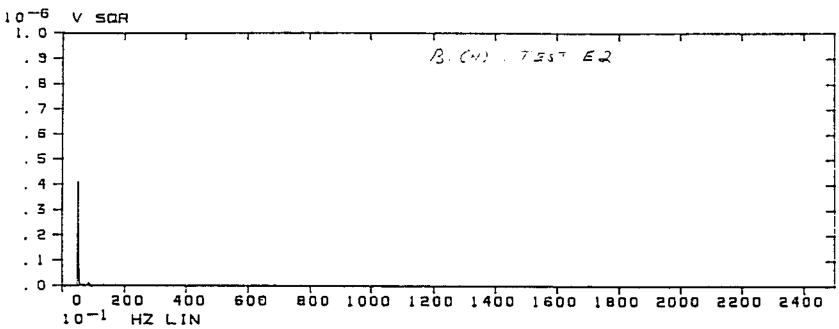
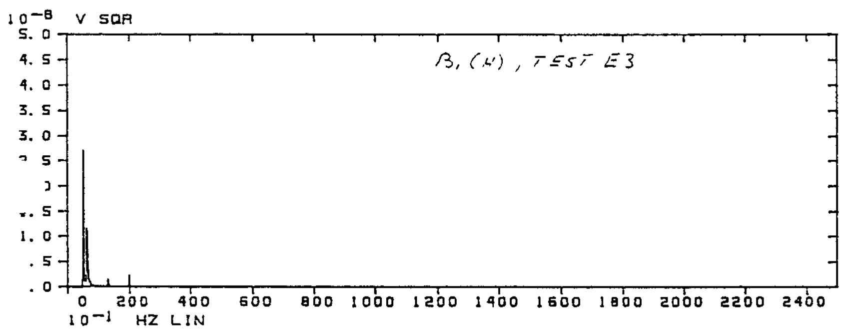
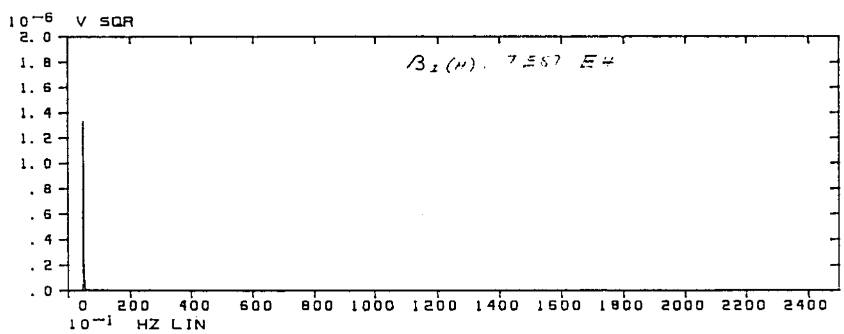
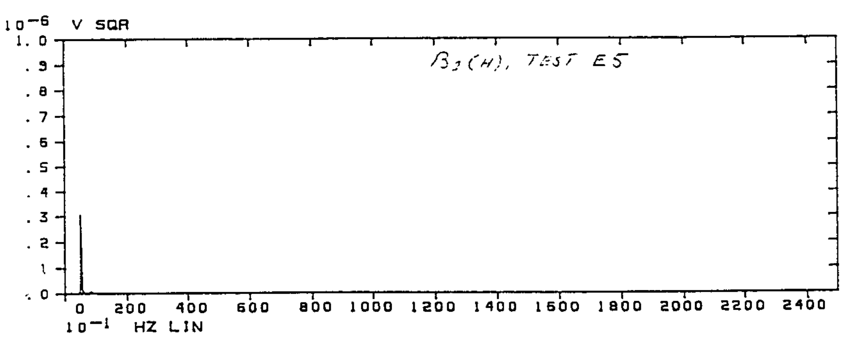
5.15×10^{-6}

5.82×10^{-7}

2.45×10^{-6}

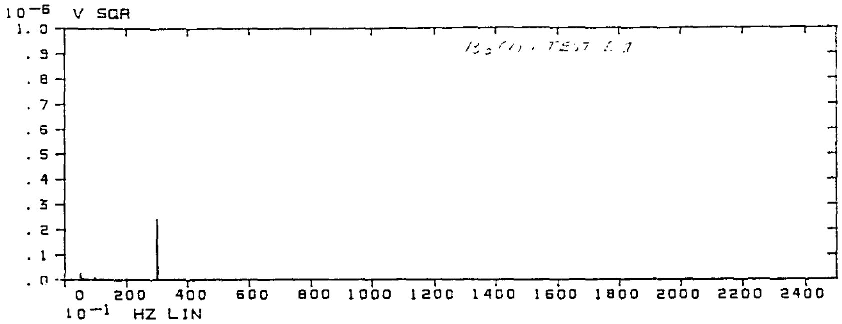
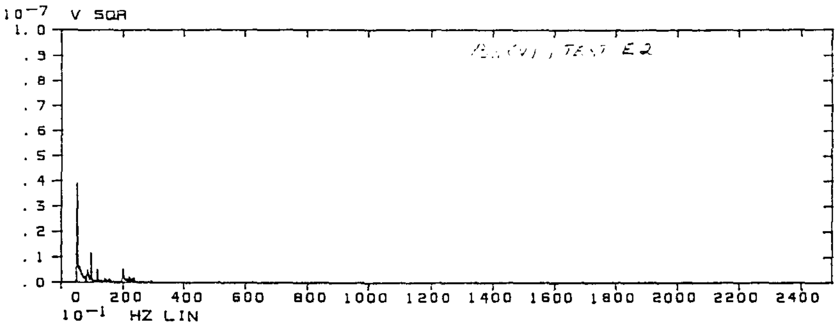
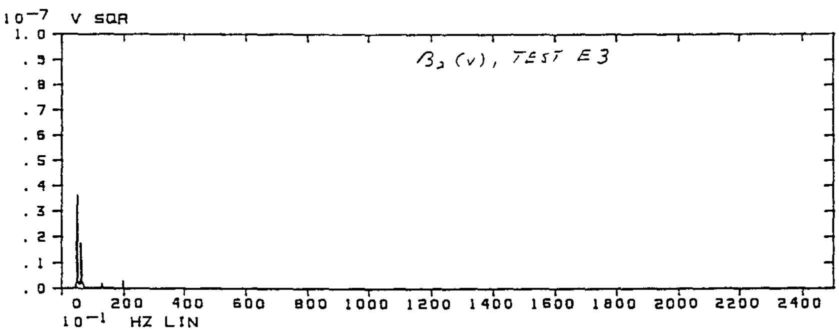
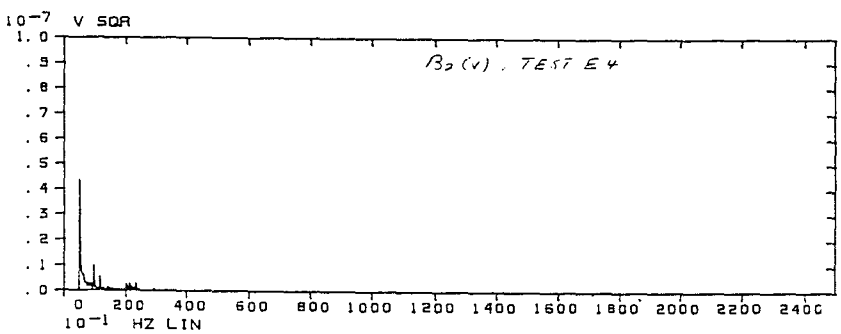
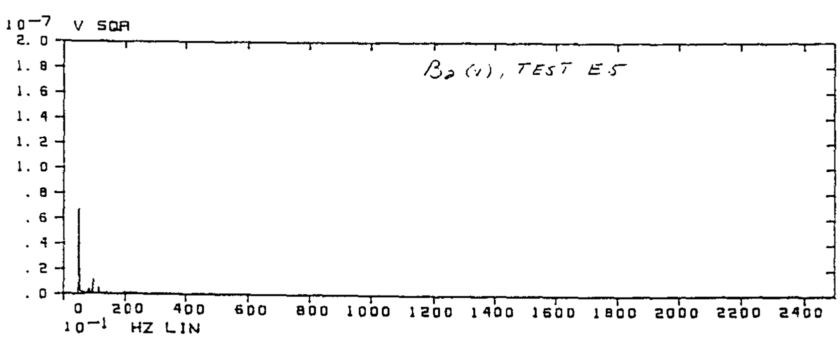
1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operational
4) 30 Hz Off

Test B, Disp. [A_9(V) On High ~ay Floor, West of A_6

		CONDITIONS			
Plot	in.$_{RMS}$	30 Hz	H_2O	BM	QM
	7.61×10^{-6} 5.06×10^{-7} 1.01×10^{-6}	On	On	Off	Off
	7.22×10^{-6} 3.86×10^{-8} 9.69×10^{-7}	Off	On	Off	Off
	2.3×10^{-6} 3.03×10^{-8} 7.43×10^{-7}	Off	On	On 1500A	Off
	1.14×10^{5} 4.84×10^{-8} 9.08×10^{-7}	Off	On	Off	On 250A
	6.76×10^{-6} 3.64×10^{-8} 8.63×10^{-7}	Off	Off	Off	Off

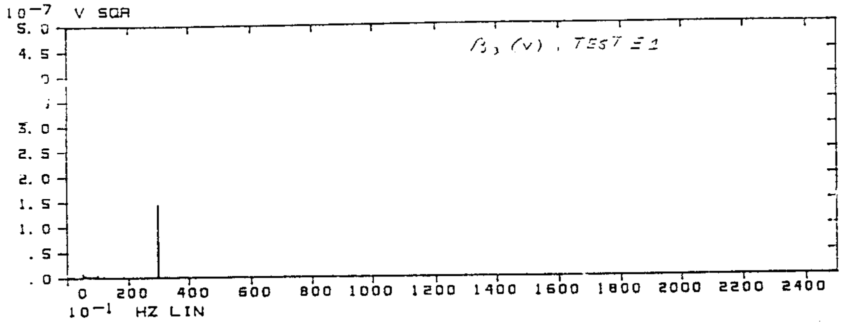
Test E, Disp. [B_1(H)], On Bending Magnet

CONDITIONS

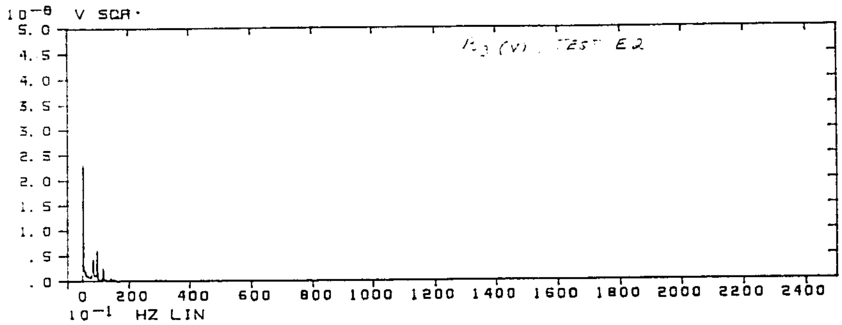
	in. RMS	30 Hz	H_2O	BM	QM
	5.96×10^{-6} 4.56×10^{-6} 2.16×10^{-6}	On	On	Off	Off
	3.77×10^{-6} 3.65×10^{-7} 2.10×10^{-6}	Off	On	Off	Off
	2.66×10^{-6} 2.95×10^{-8} 8.12×10^{-7}	Off	On	On 1500A	Off
	3.87×10^{-6} 3.75×10^{-7} 2.04×10^{-6}	Off	On	Off	On 250A
	3.60×10^{-6} 3.59×10^{-7} 1.86×10^{-6}	Off	Off	Off	Off

Test E, Disp. [B_2(V)] On Bending Magnet

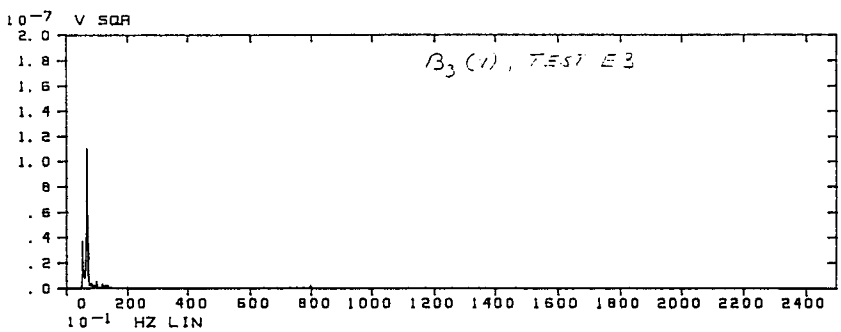
CONDITIONS



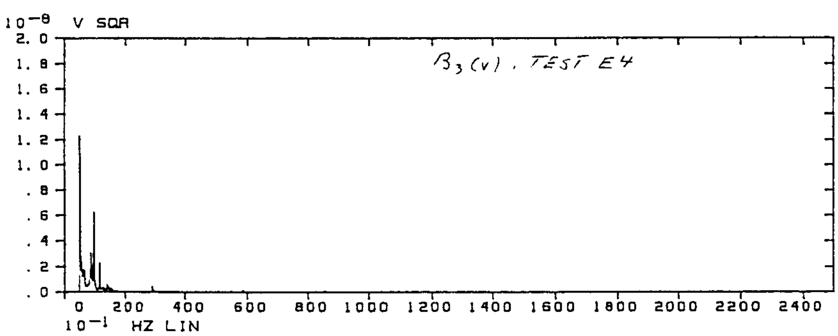
in. RMS	30 Hz	H_2O	BM	QM
4.19×10^{-6} 3.57×10^{-6} 1.06×10^{-6}	On	On	Off	Off



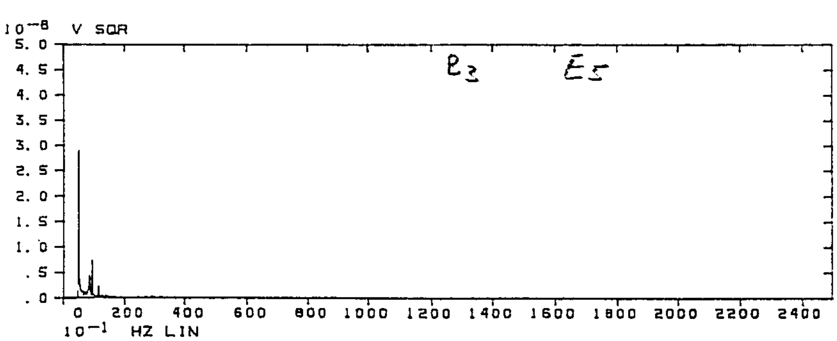
in. RMS	30 Hz	H_2O	BM	QM
2.34×10^{-6} 2.45×10^{-7} 8.89×10^{-7}	Off	On	Off	Off



in. RMS	30 Hz	H_2O	BM	QM
5.24×10^{-6} 2.51×10^{-7} 1.72×10^{-6}	Off	On	On 1500A	Off



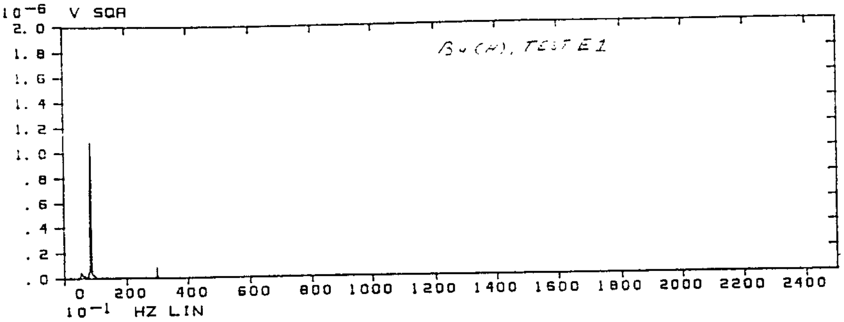
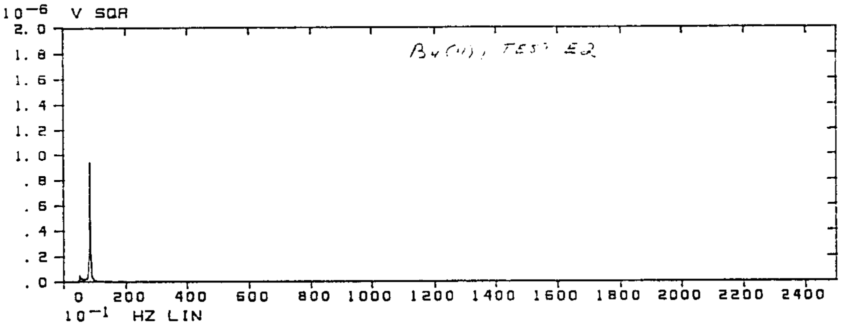
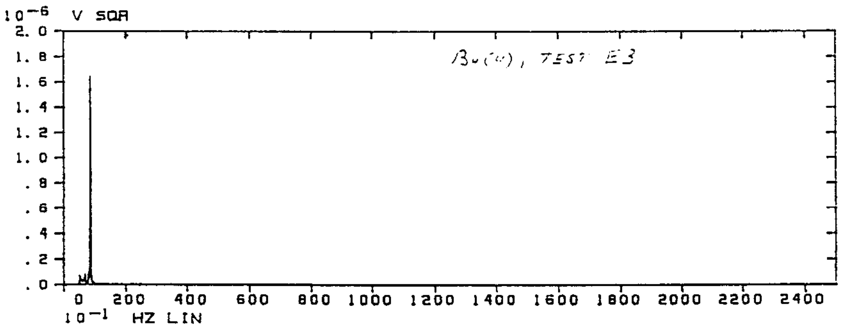
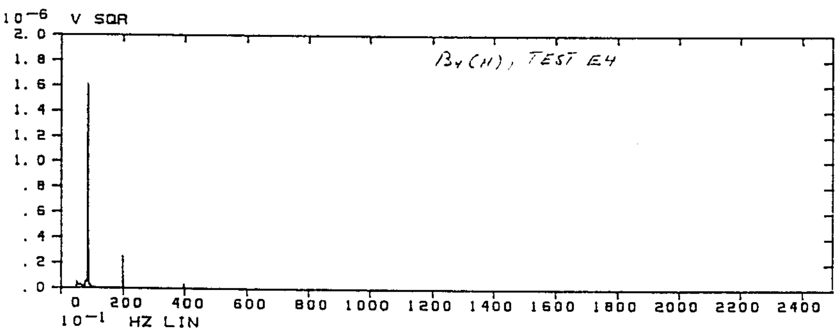
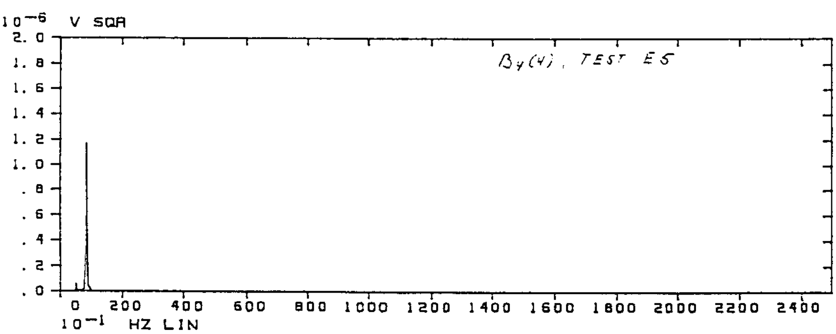
in. RMS	30 Hz	H_2O	BM	QM
2.11×10^{-6} 2.46×10^{-7} 9.02×10^{-7}	Off	On	Off	On 250A



in. RMS	30 Hz	H_2O	BM	QM
2.53×10^{-6} 2.40×10^{-7} 9.21×10^{-7}	Off	Off	Off	Off

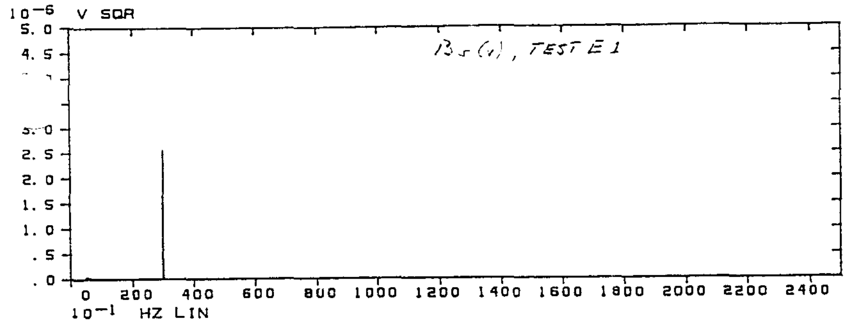
Test E, Disp. [B_3(V)] On Floor at Base of Bending Magnet

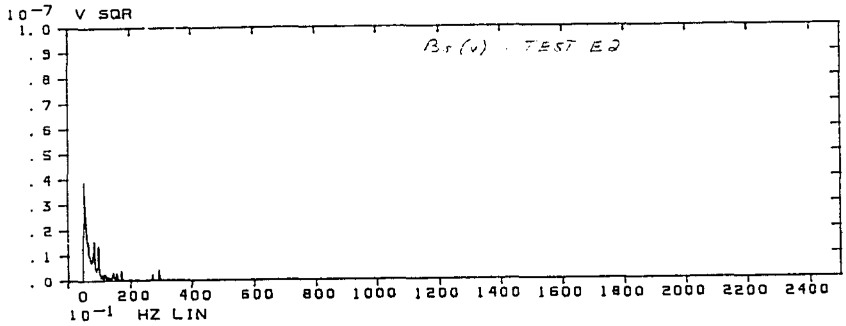
CONDITIONS

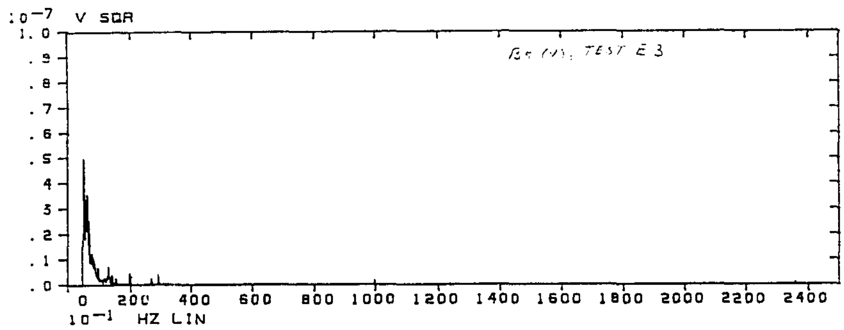
	in. RMS	30 Hz	H_2O	BM	QM
	1.19×10^{-5} 2.68×10^{-6} 1.63×10^{-6}	On	On	Off	Off
	1.22×10^{-5} 1.76×10^{-7} 1.80×10^{-6}	Off	On	Off	Off
	1.40×10^{-5} 1.79×10^{-7} 2.47×10^{-6}	Off	On	On 1500A	Off
	1.45×10^{-5} 2.25×10^{-7} 5.4×10^{-6}	Off	On	Off	On 250A
	1.23×10^{-5} 1.54×10^{-7} 1.04×10^{-6}	Off	Off	Off	Off

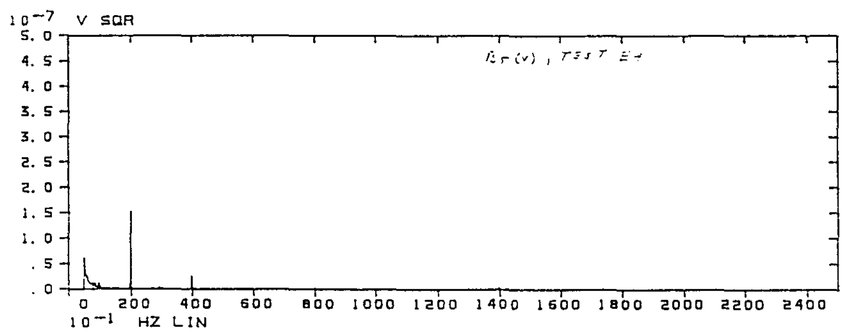
Test E, Disp. [B_4(H)] On QM 2001

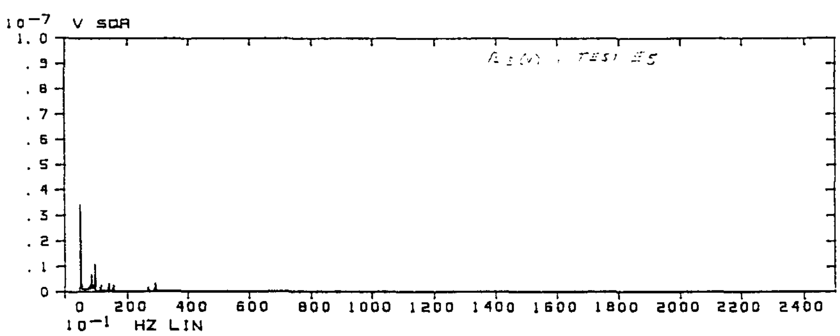
BM







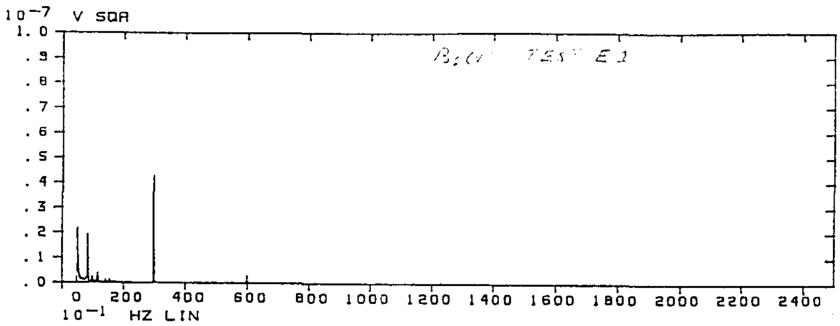


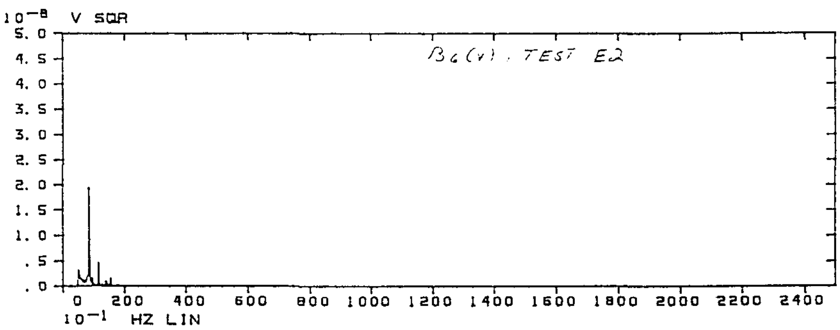


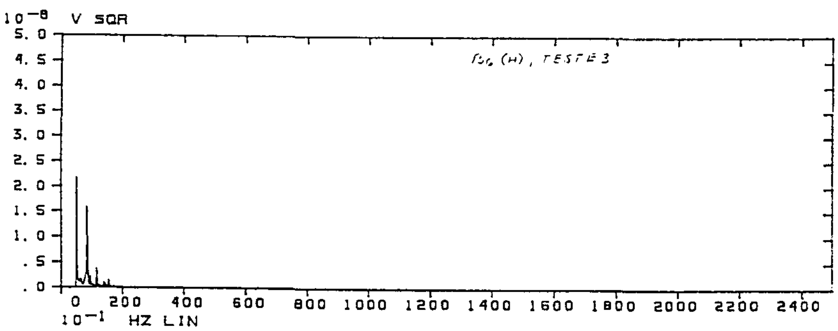
CONDITIONS

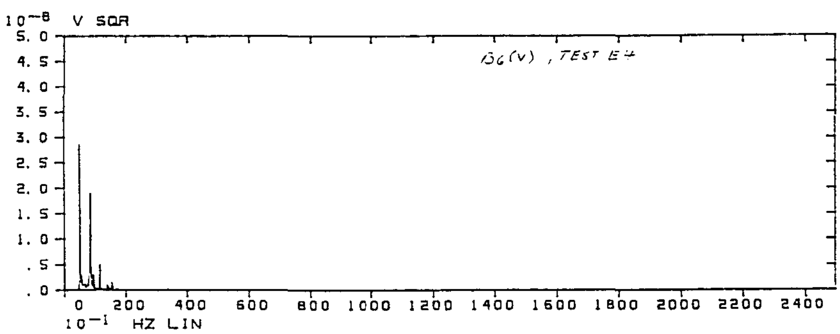
in.$_{RMS}$	30 Hz	H_2O	BM	QM
1.53×10^{-5} / 1.42×10^{-5} / 2.58×10^{-6}	On	On	Off	Off
5.03×10^{-6} / 7.55×10^{-7} / 2.16×10^{-6}	Off	On	Off	Off
5.88×10^{-6} / 7.74×10^{-7} / 2.44×10^{-6}	Off	On	On 1500A	Off
6.81×10^{-6} / 7.46×10^{-7} / 4.55×10^{-6}	Off	On	Off	On 250A
2.94×10^{-6} / 7.06×10^{-7} / 1.42×10^{-6}	Off	Off	Off	Off

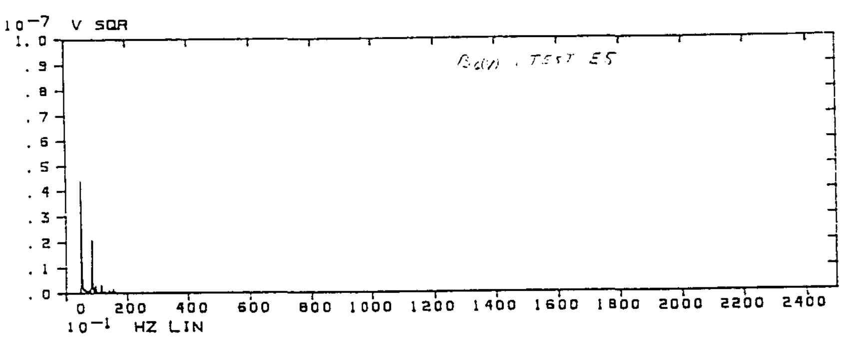
Test E, Disp. [B_5(V)] On QM 2001









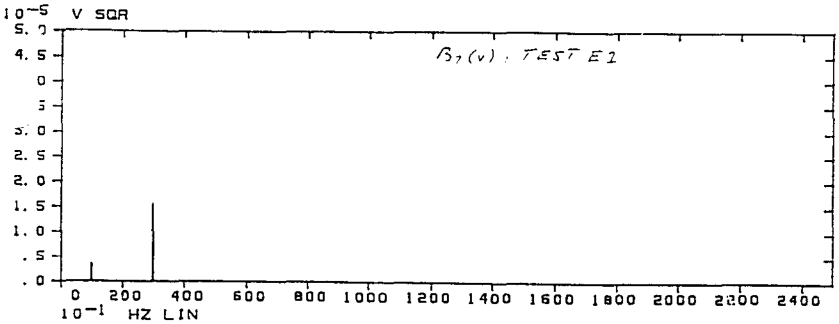


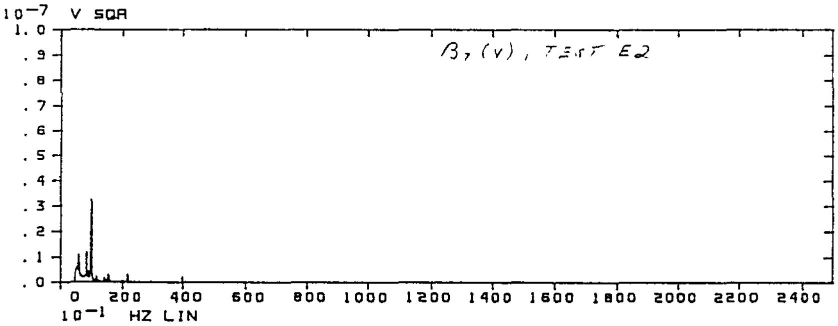
	CONDITIONS			
in.$_{RMS}$	30 Hz	H_2O	BM	QM
3.35×10^{-6} 1.89×10^{-6} 1.26×10^{-6}	On	On	Off	Off
2.28×10^{-6} 1.11×10^{-7} 1.06×10^{-6}	Off	On	Off	Off
2.58×10^{-6} 1.24×10^{-7} 1.05×10^{-6}	Off	On	On 1500A	Off
2.79×10^{-6} 1.33×10^{-7} 1.08×10^{-6}	Off	On	Off	On 250A
2.94×10^{-6} 1.22×10^{-7} 1.05×10^{-6}	Off	Off	Off	Off

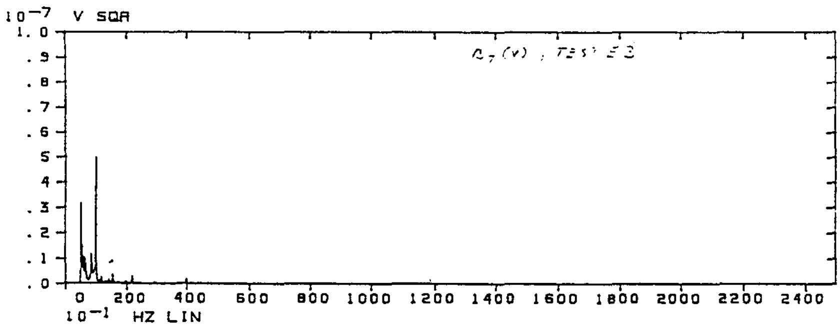
Test E, Disp. [B_6(V)] On Floor at Base of QM 2006

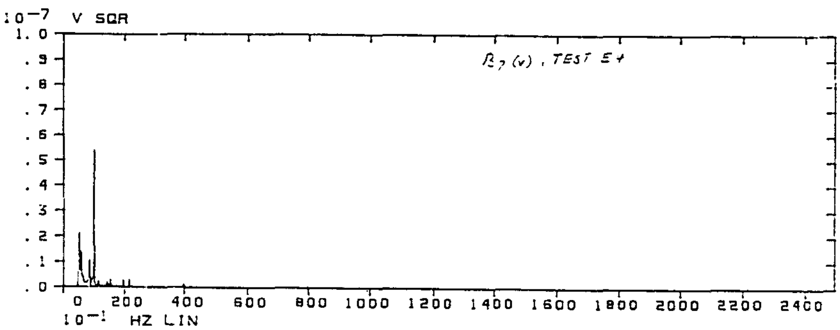
B21

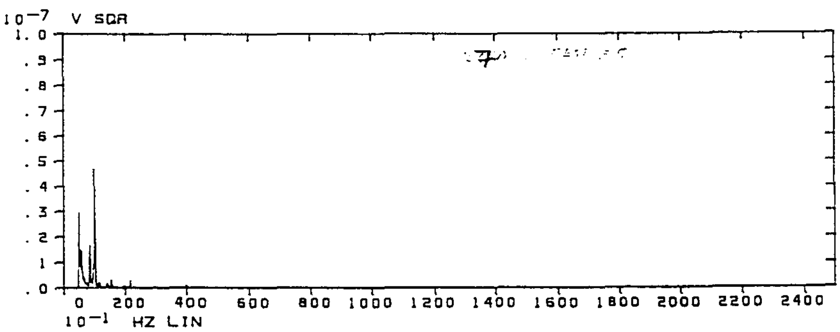
CONDITIONS











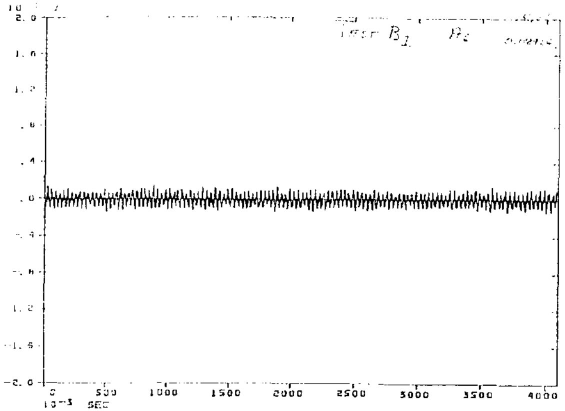
in. RMS	30 Hz	H_2O	BM	QM
4.02×10^{-5} 3.57×10^{-5} 5.46×10^{-6}	On	On	Off	Off
3.66×10^{-6} 3.23×10^{-7} 1.72×10^{-6}	Off	On	Off	Off
4.24×10^{-6} 3.00×10^{-7} 1.70×10^{-6}	Off	On	On 1500A	Off
3.93×10^{-6} 3.39×10^{-7} 1.67×10^{-6}	Off	On	Off	On 250A
4.20×10^{-6} 3.30×10^{-7} 2.09×10^{-6}	Off	Off	Off	Off

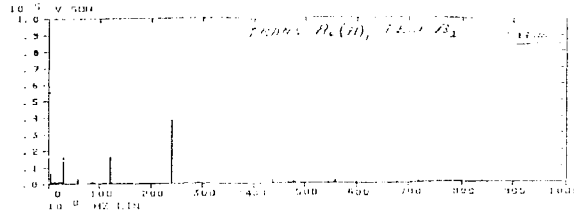
Test E, Disp. [B_7(V)] On Floor Near Storage Ring Magnets

APPENDIX C

Test Series B -

Acceleration-time signals, PSDs, and RMS values - Frequency range 5 to 1,000 Hz



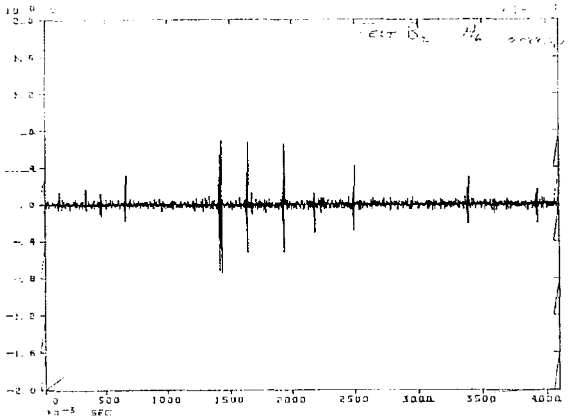


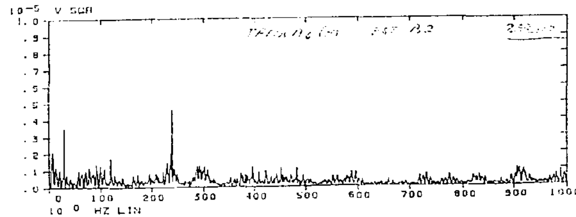
G_{RMS}

5.17×10^{-5}

CONDITIONS

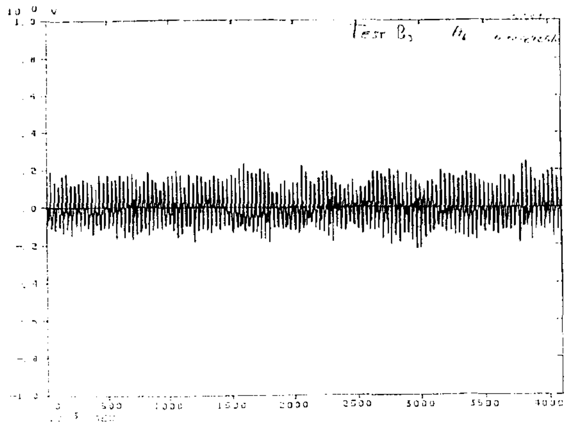
1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On

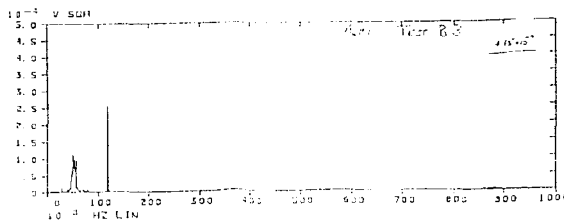




8.42×10^{-3}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered Over A_6,A_7 (Instrumented "I" Beam)
4) 30 Hz On

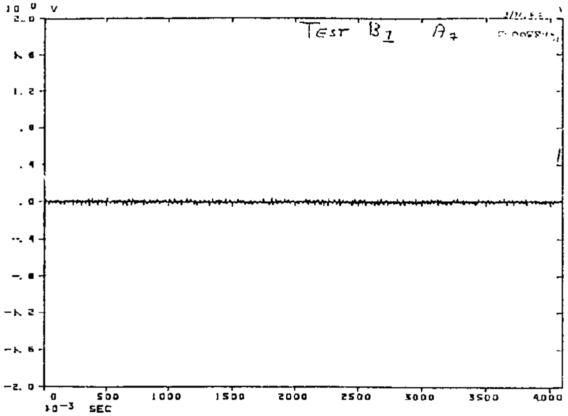


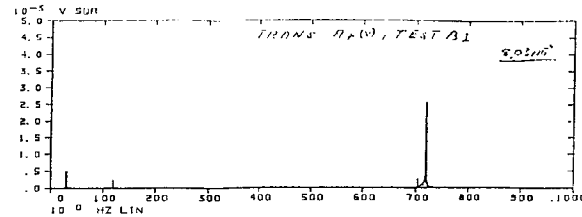


4.15×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operating
4) 30 Hz Off

Test B, Acc. A_6(H), On "I" Beam Supporting Crane Rail



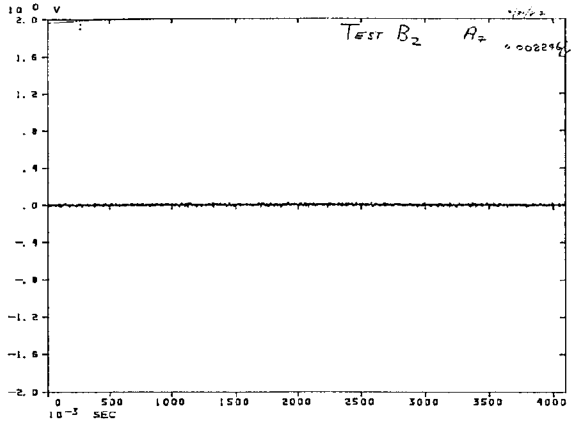


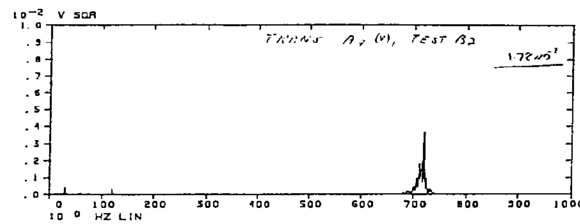
G_{RMS}

CONDITIONS

8.03×10^{-4}

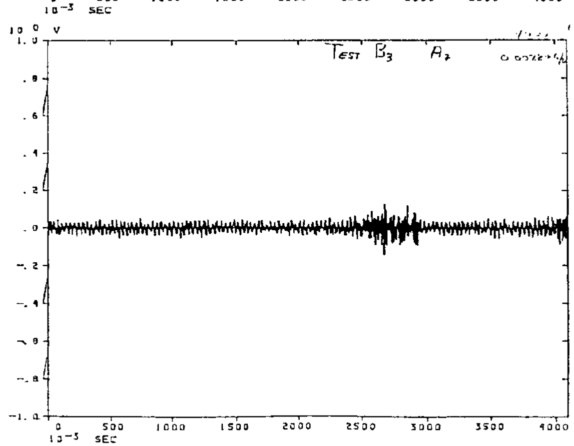
1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On

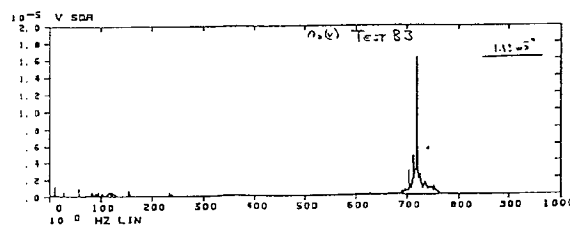




1.78×10^{-3}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered Over A_6,A_7 (Instrumented "I" Beam)
4) 30 Hz On

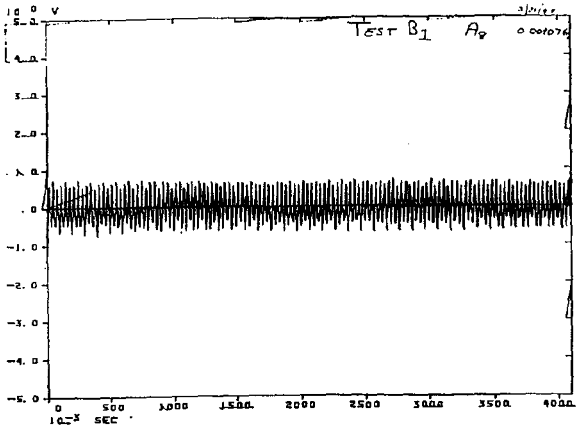
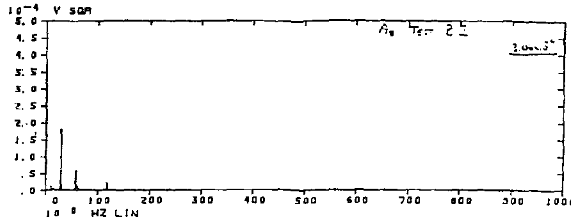
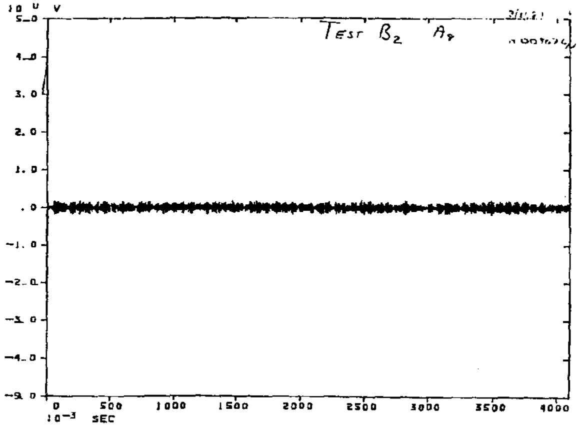
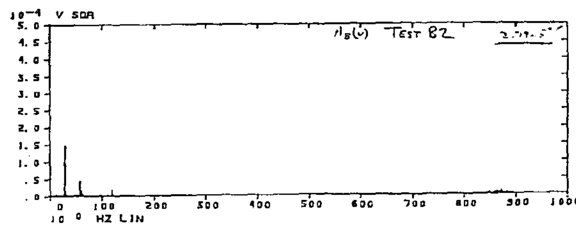
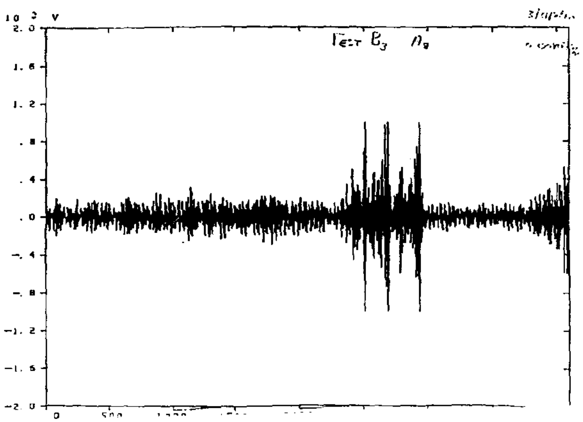
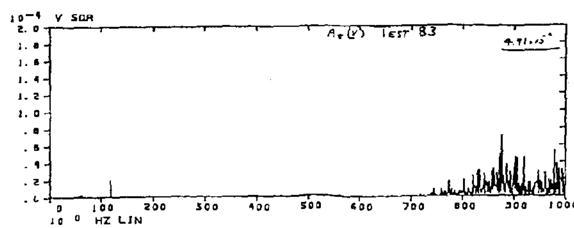




1.13×10^{-4}

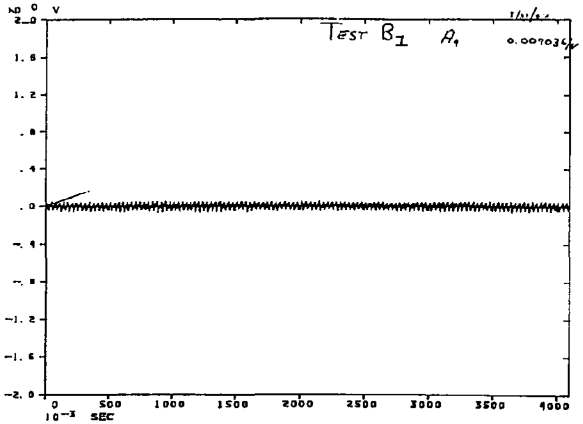
1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operating
4) 30 Hz Off

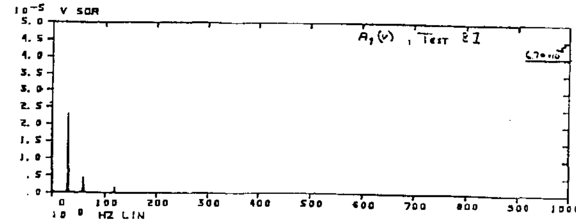
Test B, Acc. A_7(V), On High-Bay Floor (Base of "I" Beam, Near A_6(H))

		G_{RMS}	CONDITIONS
		3.06×10^{-4}	1) IPNS Not Operating (Normal Building Activity) 2) Fans On 3) Crane Operating at East End of High-Bay (Near A_8) 4) 30 Hz On
		2.79×10^{-4}	1) IPNS Not Operating (Normal Building Activity) 2) Fans On 3) Crane Operation Centered Over A_6,A_7 (Instrumented "I" Beam) 4) 30 Hz On
		4.91×10^{-4}	1) IPNS Not Operating (Normal Building Activity) 2) Fans On 3) Crane Not Operating 4) 30 Hz Off

Test B, Acc. A_8(V) On High-Bay Floor, Near East Crane "I" Beam

CONDITIONS

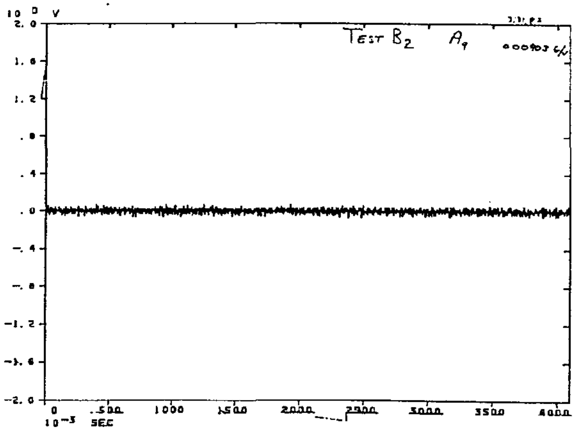


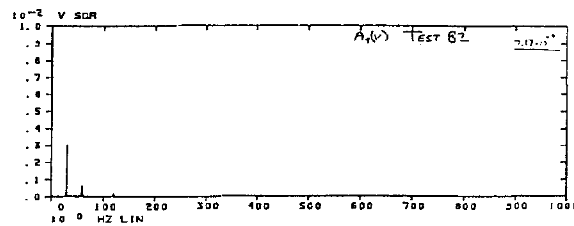


G_{RMS}

6.70×10^{-5}

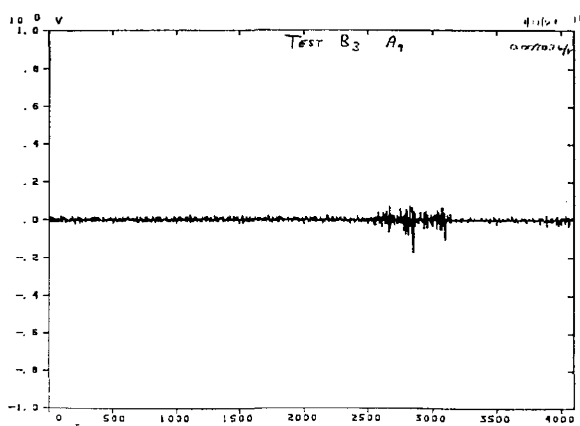
1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operating at East End of High-Bay (Near A_8)
4) 30 Hz On

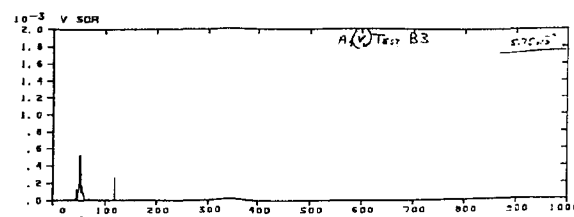




7.17×10^{-4}

1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Operation Centered Over A_6,A_7 (Instrumented "I" Beam)
4) 30 Hz On





5.75×10^{-4}

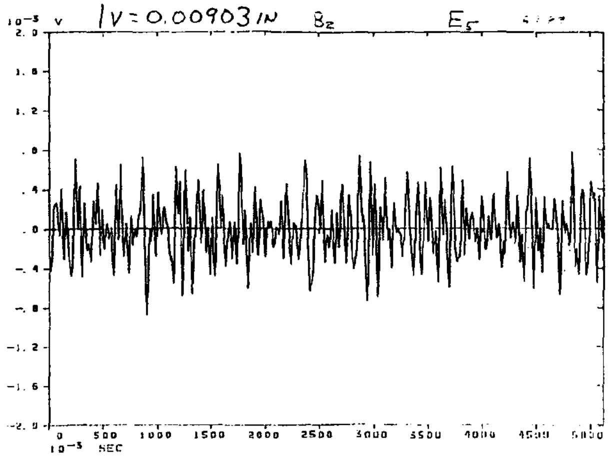
1) IPNS Not Operating (Normal Building Activity)
2) Fans On
3) Crane Not Operating
4) 30 Hz Off

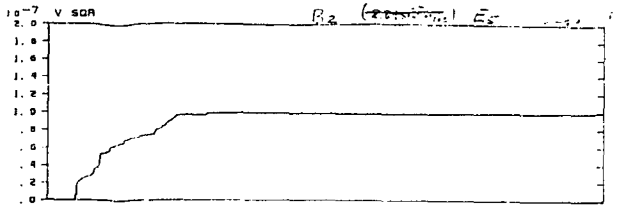
Test B, Acc. A_9(V), On High-Bay Floor, West of A_6

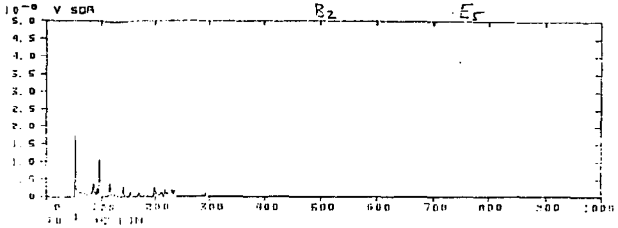
APPENDIX D

Test Series E

Displacement-time signals, PSDs, and rms values - Frequency range 5 to 100 Hz

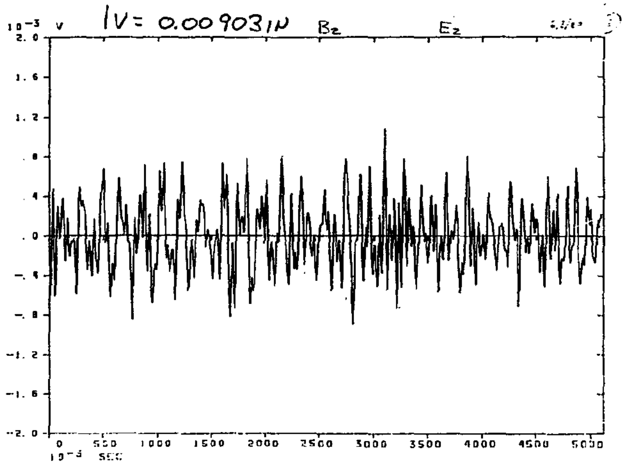


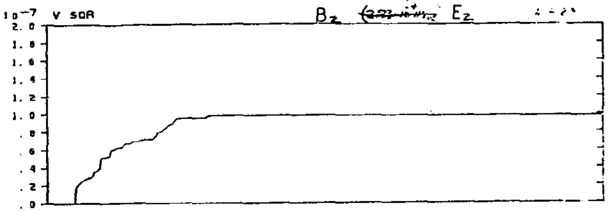


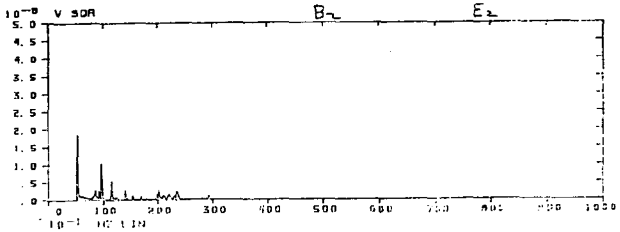


E5 Baseline (coolant flow off, no magnets energized)

3.6×10^{-6} $in._{RMS}$
(0.090 µm)

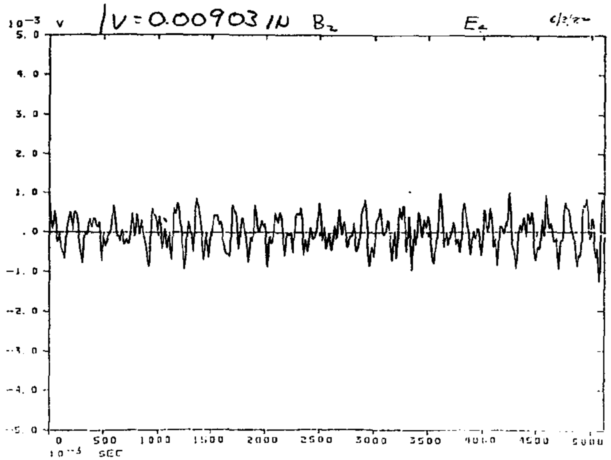


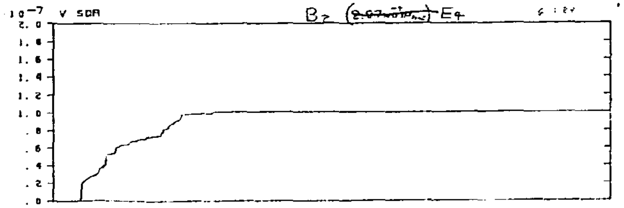


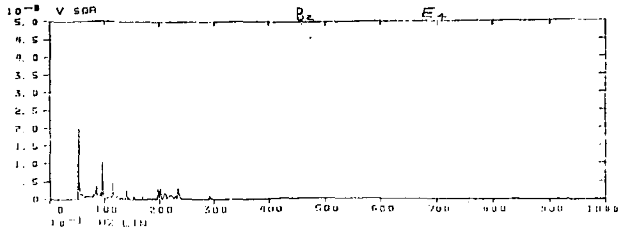


E2 Coolant flow on, magnets not energized

3.77×10^{-6} $in._{RMS}$
(0.094 µm)

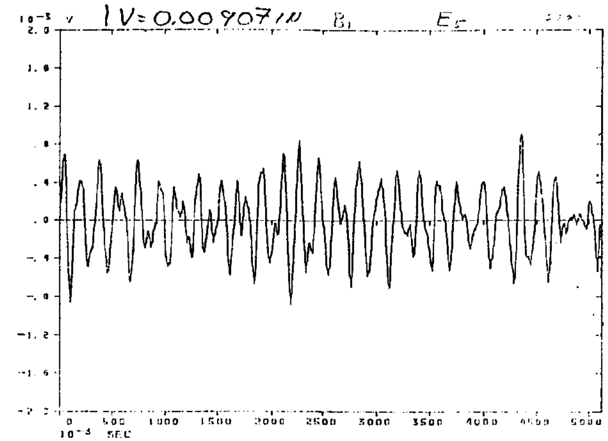


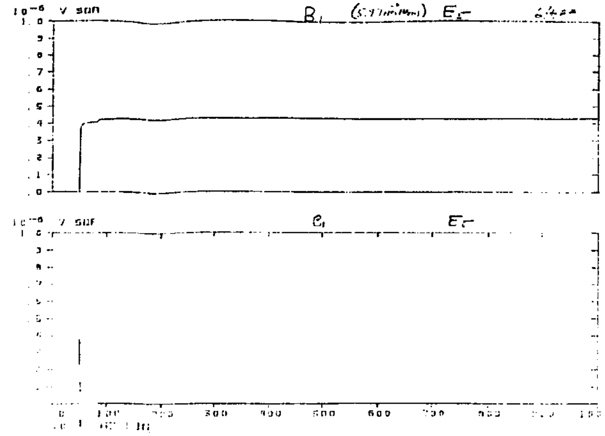




E4 Coolant flow on, QMs energized

3.87×10^{-6} $in._{RMS}$
(0.097 µm)

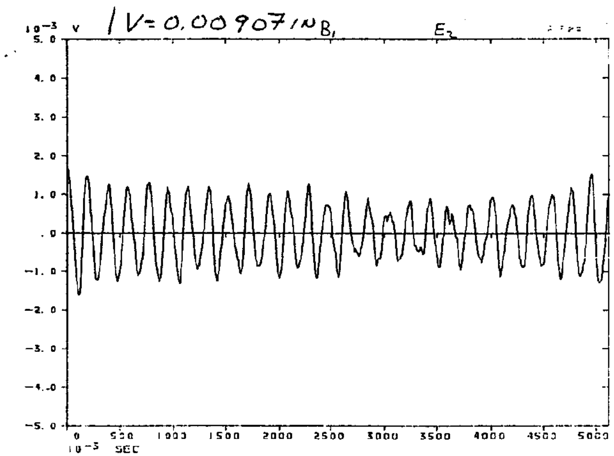


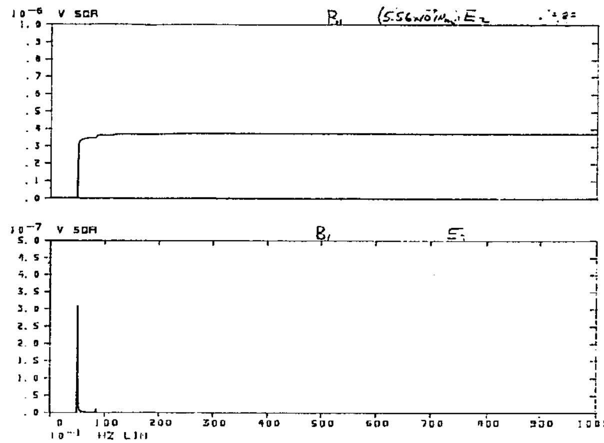


E5

Baseline (coolant flow off, no magnets energized)

6.76×10^{-6} $in._{RMS}$
(0.169 µm)

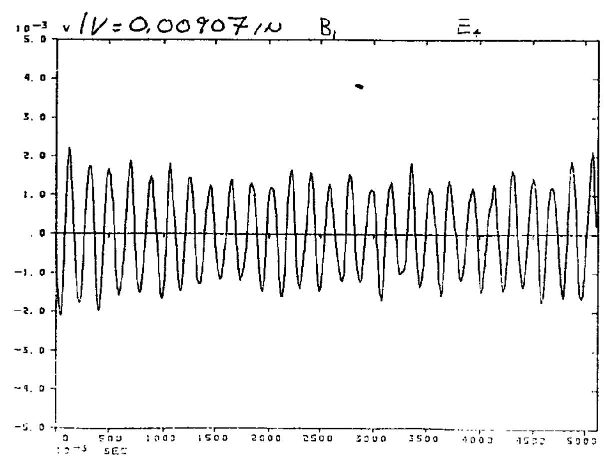


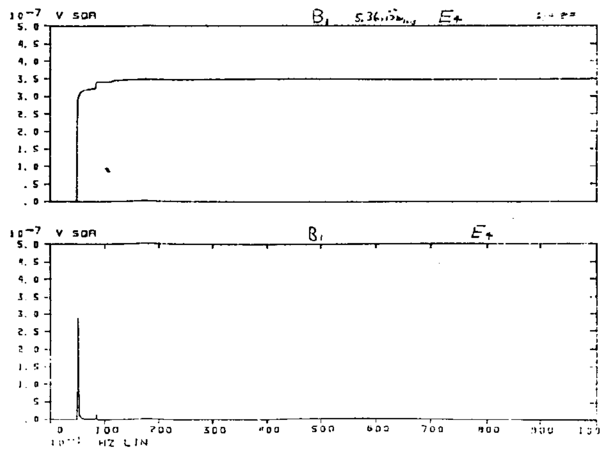


E2

Coolant flow on, magnets not energized

7.22×10^{-6} $in._{RMS}$
(0.180 µm)

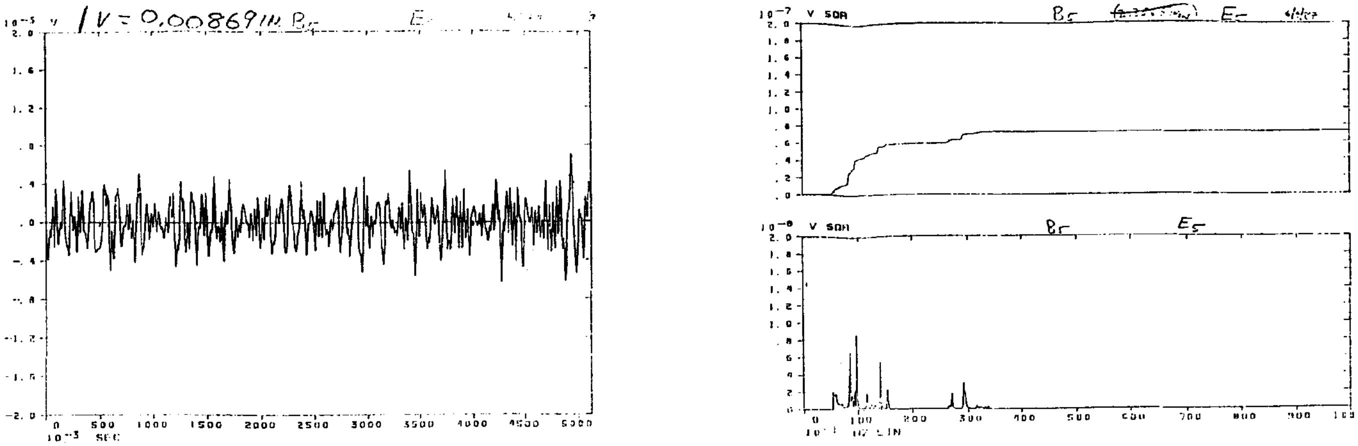




E4

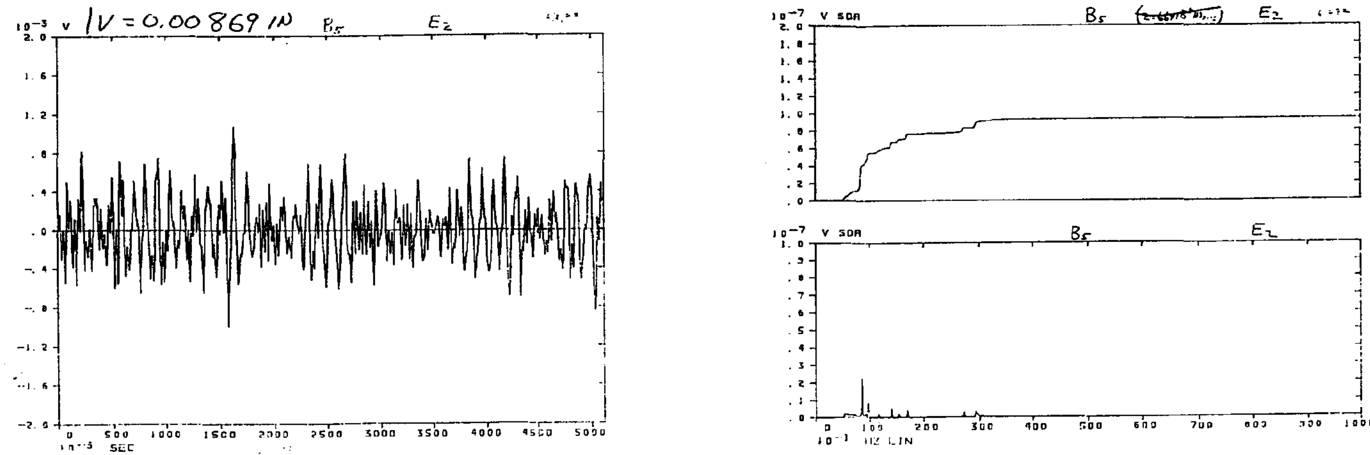
Coolant flow on, QMs energized

1.14×10^{-5} $in._{RMS}$
(0.285 µm)



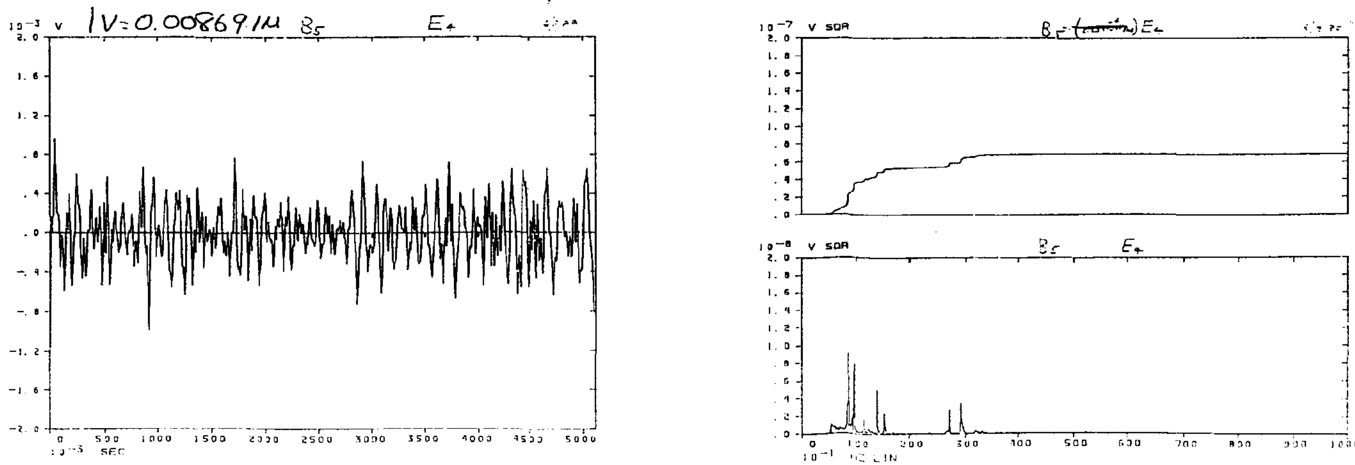
E5 Baseline (coolant flow off, no magnets energized)

2.94×10^{-6} in.$_{RMS}$
(0.073 μm)



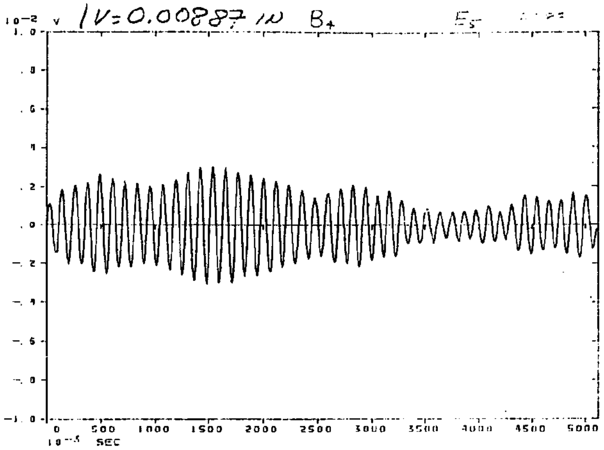
E2 Coolant flow on, magnets not energized

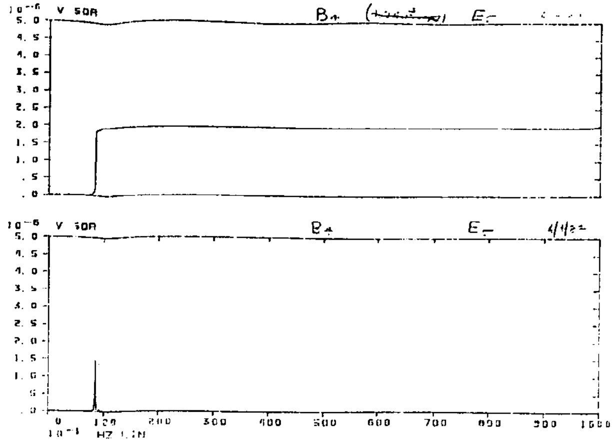
5.03×10^{-6} in.$_{RMS}$
(0.126 μm)



E4 Coolant flow on, QMs energized

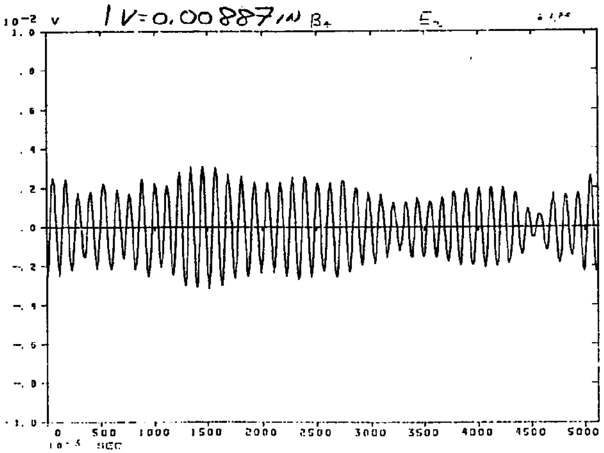
6.81×10^{-6} in.$_{RMS}$
(0.170 μm)

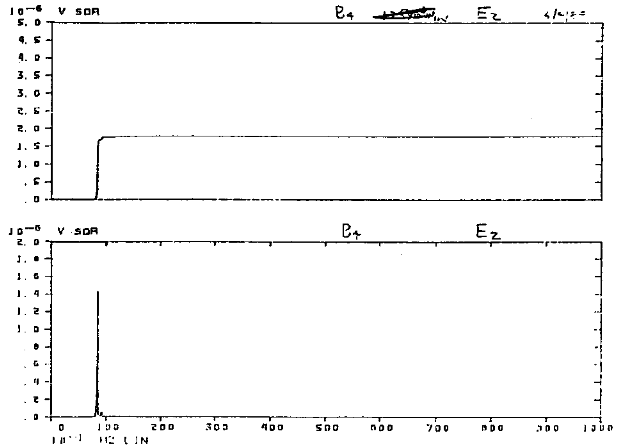




E5 Baseline (coolant flow off, no magnets energized)

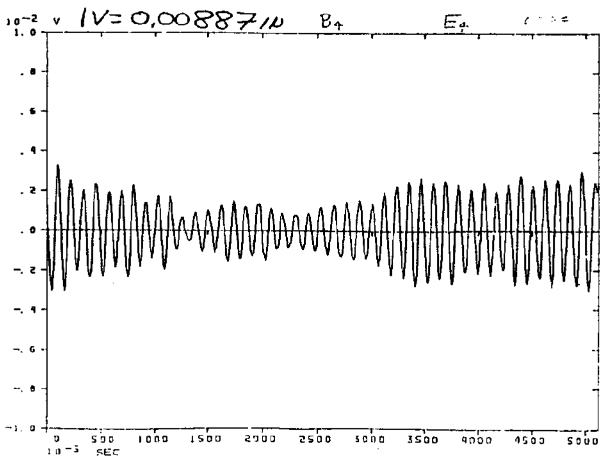
1.23 x 10^{-5} in.$_{RMS}$
(0.308 μm)

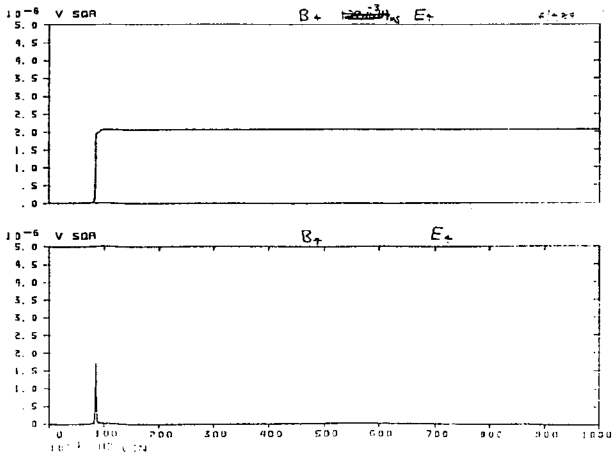




E2 Coolant flow on, magnets not energized

1.22 x 10^{-5} in.$_{RMS}$
(0.305 μm)





E4 Coolant flow on, QMs energized

1.45 x 10^{-5} in.$_{RMS}$
(0.362 μm)